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THE UNIVERSITY OF ALBERTA

EFFECTS OF SOIL K, ADDED KCL AND COMMON ROOT ROT ON BARLEY YIELD AND K UPTAKE WITH AND WITHOUT FUMIGATION

by

RENE JOSEPH LABBE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

IN

AGRONOMY

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EDMONTON, ALBERTA

FALL 1987

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(SIGNED) René J. Labbé

PERMANENT ADDRESS:

P.O. BOX 1048
FALHER, ALTA.
T0H 1M0

DATE: October 13, 1987

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled
EFFECTS OF SOIL K, ADDED KCL AND COMMON ROOT ROT ON BARLEY YIELD AND K UPTAKE WITH AND WITHOUT FUMIGATION

submitted by RENÉ JOSEPH LABBE
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE
in AGRONOMY

J. A. Robertson
Supervisor

W. J. Dudas

DATE: Oct. 9, 1987

ABSTRACT

Six loamy textured topsoil samples from central Alberta were used in four greenhouse growth trials with barley (Hordeum vulgare) to assess their K fertility. Included as original treatments were mid and high rates of added KCl and a 'control' (N, P, Mg and S added to all). Soil fumigation with chloroform was done before seeding crop 2 to reduce levels of common root rot (CRR) in two soils. All six soils were fumigated before seeding crop 3, but not again before crop 4.

In crop 1, top growth (yield) of barley was affected by added KCl, exchangeable K and CRR. Yields varied much more among the soils than the KCl treatments, while CRR varied markedly among the soils and had significant negative effects on yields and K uptake. Fumigation of the two soils which had the most severe CRR reduced its severity, and increased yields in crop 2 more than did added KCl. Fumigation of all pots before crop 3 reduced considerably the variabilities in K uptake, yield and CRR severity among soils compared to crop 1. Fumigation suppressed CRR, so that yields on the KCl treatments approached a common maximum for all soils, yet a CRR effect on crop 3 yields approached significance. Variation in yields and CRR severity among soils increased from crops 3 to 4. CRR had significant negative effects on barley yield and K uptake in crop 4, whereas exchangeable K had positive effects. Results from a soil fumigation and incubation experiment showed that exchangeable K was not affected significantly by chloroform fumigation, which reduced, but did not eradicate, viable spores of Bipolaris sorokiniana (the main CRR pathogen).

This work suggests that when CRR is severe, K fertility and the nutritional benefits of KCl to barley are confounded by a CRR effect. Besides the nutritional benefits of KCl to plants, the barley in crops 1 and 4 also benefited from suppression of CRR by KCl, but the extent to which either effect benefited growth is unknown. The possibility that CRR has affected the results of previous fertility studies was raised.

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TABLE OF CONTENTS

CHAPTER		PAGE
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	3
2.1.0	K Fertility Work in the Prairies and the Northern Great Plains	3
2.1.1	Research in Alberta and Saskatchewan before 1958	3
2.1.2	Research in the Prairies from 1958 to 1978	3
2.1.3	K Fertility Research from 1978 to 1986	7
2.2.0	Assessing Plant Available K of Soils: Success of Methods	11
2.2.1	Measuring K of the Soil Solution	10
2.2.2	Determining Exchangeable and Non-exchangeable Soil K	11
2.2.3	Soil K Buffer Curves and EUF Measurements	14
2.2.4	Implications of Simulating Plant K Uptake	17
2.3.0	Dryland Common Root Rot of Small Grains	18
2.3.1	Disease Distribution, Symptoms and Causal Agents	18
2.3.2	Description and Epidemiology and B. sorokiniana	19
2.3.3	Effects of Management and Fertilizer N and P on Root Rot	21
2.3.4	Effects of KCl on Common Root Rot	23
2.4.0	Summary	24
3.	MATERIALS AND METHODS	27
3.1.	Description of Sites, Soil Collection and Analysis	27
3.2.	Greenhouse Experiment	28
3.3.	Soil Incubation Experiment	30
3.4.	Statistical Analyses	31
4.	RESULTS AND DISCUSSION	33
4.1.	Chemical and Physical Characterization of Soils	33
4.2.	Observations and Analysis Of Barley Crop No. 1	35
4.3.	Observations and Analysis Of Barley Crop No. 2	42
4.4.	Observations and Analysis Of Barley Crop No. 3	47
4.5.	Effects of Fumigation on Soil K and Root Rot Fungi	51
4.6.	Observations and Analysis Of Barley Crop No. 4	55
4.7.	Correlation of Barley Variables With Soil K and Root Rot	60
4.8.	Exchangeable K, Successive Cropping and K Uptake	62
4.9.	Effect of Fertilizer KCl on Barley Root Rot	63
5.	SUMMARY AND CONCLUSIONS	66
6.	REFERENCES	70

LIST OF TABLES

Table		Page
1.	Sites, owners, textures and parent materials of soils	28
2.	Some physical and chemical properties of study samples before cropping	34
3.	Exchangeable soil K measured before and after each crop, along with barley K uptake, for crops 1 and 2	36
4.	Analysis of variance of data for crop 1	39
5.	Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 1 (control pots only).....	39
6.	Analysis of variance of data for crop 2	46
7.	Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 2 (control pots only)	46
8.	Analysis of variance of data for crop 3	50
9.	Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 3 (control pots only).....	50
10.	Analysis of variance of exchangeable soil K and Bipolaris sorokiniana spore count data from incubation experiment	53
11.	Mean barley K uptake (mg/kg soil) and mean exchangeable K (mg/kg) of 4 crops	58
12.	Analysis of variance of data for crop 4	59
13.	Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 4 (control pots only)	59

LIST OF FIGURES

Figure		Page
1.	Mean dry matter yields (3 reps) of barley from crop 1 for all combinations of KCl treatments and surface Ap samples	38
2.	Mean root rot severities (3 reps) on barley of crop 1 for all combinations of KCl treatments and surface Ap samples	38
3.	Mean dry matter yields (3 reps) of barley from crop 2 for all combinations of KCl treatments and surface Ap samples	44
4.	Mean root rot severities (3 reps) on barley of crop 2 for all combinations of KCl treatments and surface Ap samples	44
5.	Mean dry matter yields (3 reps) of barley from crop 3 for all combinations of KCl treatments and surface Ap samples	48
6.	Mean root rot severities (3 reps) on barley of crop 3 for all combinations of KCl treatments and surface Ap samples	48
7a.	Mean exchangeable NaOAc-K of fumigated and non-fumigated soil samples 4 and 6, at 3 different incubation times	52
7b.	Mean exchangeable NaOAc-K of fumigated and non-fumigated soil samples 2 and 3, at 3 different incubation times	52
8.	Mean dry matter yields (3 reps) of barley from crop 4 for all combinations of KCl treatments and surface Ap samples	56
9.	Mean root rot severities (3 reps) on barley of crop 4 for all combinations of KCl treatments and surface Ap samples	56
10.	Comparison among KCl treatment means of root rot severity for each barley crop; significance of differences denoted (control vs mid and high) are *=0.05, **=0.01	64

1. INTRODUCTION

The majority of prairie farmland in western Canada at present contains adequate plant available potassium (K) for the production of small grains and forage crops, yet the possibility of deficiencies should not be overlooked. Roughly 2 million hectares of cultivated soils are recognized as potentially K deficient, based on extractable K values that are lower than selected critical levels.

The problem of accurately measuring soil K availability to plants, however, is inherently more complex than merely designating K status by referring to some critical value(s). Differences in frequency and magnitude of crop responses to fertilizer K have been recognized (Skogley, 1985; Robertson et al., 1985). Significant crop responses to K amendments have been observed on some soils high in extractable K (Harapiak, 1979; Janke, 1979; Skogley, 1985; Fixen et al., 1986a). Conversely, crop responses to added K on some soils with test values lower than critical ones are not always observed, based on work done in Alberta (Walker, 1979; Robertson et al., 1985). A need for further specific and intensive study of the K fertility of some Alberta soils was recognized. Thus the original objectives developed for this work were 1) to study soil K fixation and barley K uptake with respect to different forms of soil K, along with some chemical and mineralogical properties of the soils; 2) to observe the effect of repeated cropping on available and slowly available K, and 3) to compare amounts of soil K measured with different extractants to K uptake by plants.

Reports of crop responses on soils with high extractable K have spurred some researchers to compare effects of fertilizing crops with and without chloride (Cl^-). Some studies have indicated that added Cl^- can significantly benefit crop growth (Robertson et al., 1985; Fixen et al., 1986a; Timm et al., 1986). Suggested effects of Cl^- include a nutritional benefit of Cl^- to plants (Fixen et al.,1986b), and a Cl^- induced suppression of root diseases of cereal crops (Beaton, 1984; Goos et al., 1987). Both suggestions are reasonable, because Cl^- additions to soils of the Interior Plains are small compared to crop removals (Fixen et al., 1986b; Goos et al.,1987), and root diseases are known to cause serious yield reductions of cereals in western Canada (Martens et al., 1984).

During the first greenhouse experiment of this study, severity of barley root rot varied considerably among soils. The study became more interdisciplinary in nature, because of a need to evaluate the effects on barley of both common root rot and soil K availability. Evaluation of K fertility required reasonable control of root rot among soils studied. Soil fumigation was chosen as a method of controlling the effect of root rot on barley and its response to added KCl. Given the implications of the effects on barley of common root rot, soil K fertility, and their possible interactions with KCl fertilizer, the following revised study objectives were developed:

1. to characterize some of the chemical and physical properties of K deficient and non-deficient soils;
2. to compare amounts of exchangeable soil K extracted with NH_4OAc and NaOAc to K uptake by barley;
3. to determine the effect(s) of repeated cropping with barley on levels of exchangeable K;
4. to examine the effects of added KCl on barley yields, K uptake and common root rot, with and without fumigation of soils;
5. to ascertain what effects, if any, soil fumigation had on common root rot and exchangeable soil K, and also assess their effects on barley growth.

2. LITERATURE REVIEW

Comprehensive reviews of the soil mineralogy, physical chemistry, biogeochemistry, and physiological functions of K^+ and Cl^- can be found in Dixon and Weed (1977), Tisdale et al. (1985), and Munson (1985). A discussion of methods which have been used to assess plant available K of soils, and a description of the symptoms, causes and epidemiology of common root rot of grasses will follow, after a review of the history of soil K fertility work, which includes recent studies from western Canada and the U.S., is presented.

2.1.0 K Fertility Work in the Prairies and the Northern Great Plains

2.1.1 Research in Alberta and Saskatchewan before 1958.

Prior to 1958, soil K deficiency in Alberta and Saskatchewan was almost unheard of, or was deemed to be of little significance. Fifty years ago though, Kohnke (1937) used Neubauer tests to assess the P and K status of some Alberta soils. The test consisted of growing 100 seeds for 2 to 3 weeks in soil samples, and then measuring nutrients in the seedlings. The data for K were presented in a table, but the results were not further analyzed. The data showed that samples from the Black and Gray Great Groups generally contained less available K than samples from southern Alberta. Given a lack of citations for the interim from Kohnke's work to 1960, presumably no detailed studies on soil K status were done in the province. Webster (1967) reviewed work conducted in the fifties in Alberta and indicated that crop yields were seldom affected by K applications, hence the soils were thought to contain sufficient K. In Saskatchewan, no responses to fertilizer K were observed over a period from 1949 to 1955 (Henry,1979).

2.1.2 Research in the Prairies from 1958 to 1978.

Since 1958, there have been reports of crop responses to added K in field trials, but responses have varied from year to year at given sites. Significant responses on 2 soils with notable peaty areas were observed in Saskatchewan (Henry, 1979), but responses at other sites on mineral soils were absent. Reports of recurrent yield responses to K amendments were first given by the "Alberta Advisory Fertilizer Committee" (Goettel, 1962). These reports were the major impetus for

the first two detailed studies on soil K status in Alberta.

In 1961, Goettel (1962) broadcast 5 levels of K, with and without N and P, at 10 sites seeded to alfalfa in the "Black and Grey soil zones" of central Alberta. Unfortunately, precipitation and soil moisture were below normal that year, so that moisture was likely more limiting than soil K if a deficiency was present. Furthermore, the limited precipitation may have failed to move the surface broadcast K into the root absorbing zone. Goettel (1962) did find, however, that soil samples from the Airdrie series close to the Dark Brown zone contained more exchangeable (NH_4OAc) and acid extractable (M HNO_3) K than samples taken further north from the Black soil zone. From results of chemical and mineralogical analyses on all samples, he concluded that the Airdrie soil had undergone less weathering and leaching than the other soils, thereby resulting in more plant available K in the former.

Two years later, Nelson (1964) conducted both greenhouse and field experiments on soils from the "Grey, Dark Grey and Black soil zones" in Alberta. In both years of his study, moisture was again limiting and no significant responses of clover or alfalfa to KCl fertilizer were observed in the field (Nelson,1964). However, in the greenhouse experiment, barley responded to added KCl on all 4 soils tested, while alfalfa responded erratically from one crop to another. In addition to better growing conditions in the greenhouse than in the field, Nelson (1964) also attributed crop responses in the greenhouse to K uptake being limited to Ap soil only, whereas roots in the field can obtain nutrients from other soil horizons. In any case, Nelson (1964) observed that crop responses were greater on soils with low in K, and indicated that further studies of K fertility in Alberta were needed.

From 1964 to 1967, field experiments were conducted at 6 locations on Grey, Dark Grey, and Black soils to determine effects of N, P, K and several site variables on barley yield (Heapy et al., 1976). Each of N, P and K fertilizers were applied yearly at 5 rates, so that yields after the first year were affected by both current and residual fertilizer nutrients (Robertson et al.,1985). The barley yield data for 17 site-years were analyzed by using multiway factorial analysis of variance which showed no significant main or interaction effects of

fertilizer K on yield (Heapy et al.,1976). In a comparable study at the same 6 sites, Webster et al. (1976) broadcast the same 5 rates of K on bromegrass-alfalfa crops for 5 consecutive years (1966-1970). Again, there were no significant effects of applied K on the forage yields for any of the site-years, even though residual effects of added K to grass-alfalfa over a 5 year period were noted for 2 sites (Webster et al., 1976).

Two fertilizer companies were also involved in fertilizer trials. During a 6 year period from 1968 to 1973, Sherritt Gordon Mines Ltd. conducted field tests across the Prairie Provinces with different placements of KCl fertilizer (Janke, 1979). Conclusions drawn from this extensive study were the following: 1) crops responded to added KCl on soils with extractable K values less than 100 ug g^{-1}; 2) responses were greater at high rates when KCl was broadcast instead of being added with the seed, and 3) barley frequently responded to K on soils with exchangeable K greater than 100 ug g^{-1} (Janke, 1979).

Western Co-operative Fertilizers Ltd. also conducted fertilizer trials in the early and late seventies with KCl (Harapiak, 1979). Results from field trials conducted in south-central Alberta from 1971 to 1974 showed that responses occurred frequently on soils with values of extractable K over 100 ug g^{-1}. From further field tests with barley and forages, Harapiak (1979) observed that responses to added K were related better to ranges in soil texture than to exchangeable K.

Agriculture Canada research stations across the Prairie Provinces were also involved in K fertility research in the sixties and early to mid seventies. Only those reports that were available are considered here. Experiments at Swift Current, Saskatchewan, were conducted from 1969 to 1973 on 3 soils recognized to be low in K, and one high in K (Read, 1979). No significant yield responses to 2 rates of K were observed. Hennig (1979) commented that significant yield responses to K application were at times obtained in the Peace River region, but mainly on organic soils in years with cool, damp spring weather. Arable soils in the Peace River area otherwise seem to contain sufficient available K to meet crop requirements (Hennig, 1979).

Over 100 field experiments were conducted out of Lacombe in the seventies by the late D.R. Walker, who examined the effects of applied

K on rapeseed and barley yields in central Alberta (Robertson et al., 1985). Walker (1979) observed a frequency of barley yield increases of 0.67 or greater when exchangeable soil K (NH_4OAc) tested less than 75 ug g^{-1}. He also remarked that rapeseed yield responded less to applied K than that of barley. Many of the K-responsive sites were observed to be alkaline, carbonated, and poorly to imperfectly drained (Robertson et al., 1985).

The effect on plant available K in rotating 3 year stands of alfalfa with wheat, oats, barley and sugar beets, for 66 years on a Dark Brown Chernozem near Lethbridge, was investigated in 1977 by Dubetz and Dudas (1981). From 1910 to 1930, 53.8 t·ha^{-1} of manure had been applied, but the additions were increased to 67.2 t·ha^{-1} per 10 year cycle in 1940 (Dubetz and Dudas, 1981). No other source of K was applied, and straw plus grain were exported from the plots at harvest. Even though cropping for 66 years reduced exchangeable K (NH_4OAc) by 28% in the top 15 cm, total soil K remained relatively unaffected (Dubetz and Dudas, 1981). The K status of the Dark Brown Chernozem was deemed still adequate to meet crop K requirements in the rotation (Dubetz and Dudas, 1981).

Since the sixties, researchers in Alberta have taken advantage of computer technology to facilitate analysis and interpretation of data. Lopetinsky (1977) processed a large data set assembled from fertilizer trials conducted in Alberta from 1968 to 1974. Lopetinsky (1977) reaffirmed that barley responded more than oats or rapeseed to added K. He indicated that significant mean yield responses were limited to soils with exchangeable (NH_4OAc) K values lower than 100 ug g^{-1}, still responses had occurred when K was higher than 100 ug g^{-1}. Larger barley responses were observed more often at imperfectly to poorly than well drained sites. Lopetinsky (1977) suggested that other soil parameters be considered to improve the accuracy of predicting soil K requirements of crops.

Computerization also facilitated mapping of data generated by the provincial testing lab (ASANL) (Kryzanowski and Laverty,1985). Cameron (1969) first developed a map showing the spatial distribution of mean exchangeable K (for townships) in the top 15 cm of Alberta cropland. A comparison of maps for each year from 1965 to 1969 revealed that the

areas of exchangeable K varied slightly from one year to the next. The highest mean soil K levels were generally associated with the Brown and Dark Brown Great Groups (>300 ug g^{-1} exchangeable K). Intermediate to low levels (400-150 ug g^{-1}) occurred in the Black Great Group, while mean K in the Gray and Dark Gray Great Groups ranged from very low (50 ug g^{-1}) to high K values (Cameron, 1969). Although soils with low exchangeable K (<125 ug g^{-1}) are found throughout Alberta (Cameron, 1969), the majority occur in a belt 10 to 20 townships wide extending along the North Saskatchewan River from the eastern provincial border, to several ranges west of the fifth meridian. Cameron (1969) also observed smaller distinct 'pockets' of low K soils south of Calmar, east of Rocky Mountain House, between Hinton and Edson, and north of Fort Vermilion.

Kryzanowski and Laverty (1985) have recently produced similar maps of mean exchangeable K for the 0-15 cm depth using data from 1970 to 1983. The trends in spatial distribution of K levels among Great Groups were generally the same as those described by Cameron (1969). Both computer-assisted studies confirmed the trend in Kohnke's (1937) original data, which showed that available K generally decreased along a transect from southern to central Alberta. Because wide ranges of K were used in the legends of both maps, a comparison of the two can not reveal changes in soil K levels from the sixties to the seventies. A gradual decrease of exchangeable K in prairie soils since the fifties is plausible, however, because crop exports of K from Western Canada have greatly exceeded K returned by fertilization (Spratt, 1986).

2.1.3 K fertility research from 1978 to 1986.

Robertson and co-workers collected data from 1979 to 1984 for 63 site-years from 4 sets of field experiments (Robertson *et al.*, 1985). From 1979 to 1981, field trials were conducted at various sites in central (Barrhead) and east-central (Glendon) Alberta, to study effects of rates and placement of added K on barley yields and quality factors. Sites were selected based on reports of apparent K deficiencies and low soil exchangeable K (Robertson *et al.*, 1981).

The 1000 kernel weight was significantly increased at 1 site in 1979, and at 3 sites in 1980, on plots which received the initial

application of K at 250 kg·ha^{-1}; hence showing a residual effect of the high K rate (Robertson et al., 1981). The same effect was not observed on yield. Nevertheless, added K generally increased K uptake by barley in each year of the study. In the Glendon area, 5 yield responses in 6 site years were observed on soils with K test values lower than 80 ug g^{-1} prior to seeding (Robertson et al., 1985). One response was mainly due to the high K rates initially added. Only 2 significant yield responses in 9 site-years were observed in the the Barrhead area, even though the extractable K for 6 of the 9 was lower than 80 ug g^{-1}. Robertson and co-workers observed a lower frequency (0.50) of barley response to added K than that (0.66) reported earlier by Walker (1979) on soils with exchangeable K less than 80 ug g^{-1}. They also suggested that the critical value (125 ug g^{-1}) used by the Agricultural Soils and Animal Nutrition Lab (ASANL) to identify K deficient soils could be lowered.

From 1982 to 1984, Robertson and co-workers conducted three sets of field experiments with barley at 2 sites near Barrhead and 3 sites near Glendon, Alberta. The soils at the study sites were formed from medium to coarse textured fluvial materials which were poorly to imperfectly drained (Robertson et al., 1985). The objectives of their research were the following: 1) to investigate residual effects of high rates of K application; 2) to study the effect of seeding dates on crop response to K, and 3) to assess the effect of Cl^- (in KCl) on barley yield and root rot (Robertson et al., 1985). The results from 13 site-years of work addressing the third objective are discussed in section 2.3.4. Field tests with barley comparing early versus late seeding did not show that the need for K amendments is greater with early than late seeding (Robertson et al., 1985). Research from Montana though, has indicated that K diffusion limits uptake in cool semi-arid soils (Skogley, 1985), so that additions of K to these soils may be especially important to early seeded crops.

To meet objective 1, Robertson et al. (1985) examined effects on barley yields of large initial K rates (0, 250, 500, 750, kg·ha^{-1}) mixed into the Ap at all five study sites, along with effects of superimposed annual K additions (0, 25, 50 kg·ha^{-1}). In each year of the 3 year study, both initial and annual KCl treatments produced

large increases in the yield of barley grain at 3 of 5 study sites (Robertson et al., 1985). They recorded only a small barley yield response on one soil even though its extractable K was very similar to values from the responsive sites. In 1982, there were no yield responses to yearly added K among the 3 high initial rates of addition. In the 2 following years, however, annual additions of K at 30 and 60 kg ha^{-1} were required for maximum barley yields on plots which had 0 or 250 kg ha^{-1} initially soil incorporated. Tests showed that much of the initial fertilizer K was not detectable after only one year (Robertson et al., 1985). In an earlier study, MacLean and Brydon (1971) observed degrees of K fixation from 29 to 100% in eastern Canadian soils, and found that plant K uptake removed up to 64% of the K fixed against extraction with NH_4OAc. Robertson et al. (1985) concluded that the NH_4OAc soil test did not adequately measure plant available K of their soil samples from the plots that initially received high rates of K.

Much research has been done in Montana on K fertility of soils, because yield responses to added K have been frequent. Crop responses observed there occur frequently on soils which contain from 350 to more than 650 ug g^{-1} of exchangeable K (Skogley, 1985). Schaff and Skogley (1982) got a high coefficient of determination (R^2=0.88) from regression of winter wheat yields on several soil physical properties, which supports their contention that K diffusion is a key process affecting plant K availability in Montana soils. Researchers in the Dakotas have yet to implicate diffusion as the key process affecting K availability on soils high in K, where crop responses to added K have been recorded (Goos, 1984). Chloride was found to be implicated in crop responses to added KCl (Goos, 1984). For a discussion on this topic, the reader is referred to section 2.3.4.

Research into K fertility over the years has undoubtedly been complicated by inadequacies in simple soil test procedures to truly reflect K availability to plants, because of the complex nature of the problem. Recognition of the limitations of any given test method has spurred many researchers to compare suitability of established and new techniques for determining soil K status.

2.2.0 Assessing Plant Available K of Soils: Success of Methods

The major forms of inorganic soil K can be conveniently classed as non-exchangeable (90-98% of total K), exchangeable, and solution K. Compared to the first, the latter two forms are readily available to plants, but only comprise about 0.1-2% of total soil K (Tisdale et al., 1985). Potassium in organic residues is quickly released because of its relatively high solubility (Munson, 1980). Early work revealed little relationship between crop yield and total soil K, because most of it is structural K of soil minerals, which is released too slowly to meet the requirements of growing plants (Munson, 1980). Many methods which measure only a small portion of total K have been developed for assessing K availability to crops.

The effectiveness of these methods has usually been tested against plant K uptake by sequential cropping in pot experiments. Goettel (1962) and Nelson (1964) reviewed some of the earlier papers on this subject which are not considered here. The following discussion mainly addresses the performance of test methods as indices of soil K availability to plants.

2.2.1 Measuring K of the Soil Solution.

Extraction of soil K using either water or a dilute electrolytic solution has been compared to other methods of testing K availability. 'Potassium activity ratios' $[AR_K = a_K \cdot (a_{Ca} + a_{Mg})^{-.5}]$ of soil extracts have often been used instead of simple activities of K (a_K) for regression analyses with plant yield and/or K uptake data. Conyers and McLean (1969) reported that the correlation of AR_K to K uptake by alfalfa on five Ohio soils was the poorest among several indices that compared K uptake with amounts of extractable K. Correlations of AR_K with both plant K uptake and yield, on 42 Scottish and 11 Canadian soils, were also poorer than those with other K indices (Sinclair, 1982; Acquaye and MacLean, 1966; respectively). Munn and McLean (1975) obtained poor to good correlations of K uptake by corn and oats with AR_K values, but these offered no improvement over more conventional test methods.

Correlation of water soluble K with rice yield on some Indian soils was as good as correlations of yield with other forms of

extracted K (Ramanathan and Nemeth, 1982). The relationship of water soluble K to K uptake by rice was inferior to other correlations of K uptake with extractable K. In Montana, Skogley and Haby (1981) reported that one of the best correlations of winter wheat response with extractable K was with dilute electrolytes (R^2=0.53). Despite this correlation, Skogley and Haby (1981) concluded that soil K measured with dilute electrolytes in water was inadequate for testing the K availability of Montana soils. Therefore other methods have had to be considered for assessing K availability in soils.

2.2.2 Determining Exchangeable and Non-exchangeable Soil K

The K held in crystal structures of primary and secondary minerals is non-exchangeable soil K. Up to 10% of the non-exchangeable K may occur in the interlayer regions of hydrous micas, chlorites, and interstratified secondary phyllosilicates, and is considered to be slowly available to plants (Tisdale et al., 1985). In theory, exchangeable K consists of hydrated K^+ ions that are attracted to negatively charged soil surfaces, and that are in equilibrium with non-exchangeable and solution K. Exchangeable K is also operationally defined as the amount of K^+ ions that can be displaced from soil with neutral salt solutions through cation exchange (Tisdale et al., 1985). Soluble K should not, in theory, be included with exchangeable K, but the former is usually small enough in nonsaline soils to be included with the latter without introducing appreciable error to its measurement (Pratt, 1965). Use of a standard cation and pH to displace K are desirable for consistency, because of differences in exchange affinities of cations at different pH's. Although there is no universal extractant of exchangeable K, neutral, molar ammonium acetate (NH_4OAc) has been used extensively (Tisdale et al., 1985).

Many experiments have been done to compare the correlation of ammonium acetate extractable K (NH_4OAc-K) and K extracted by other methods with plant yield or K uptake. Conyers and McLean (1969) and Sinclair (1982) obtained their best correlations between extractable K and plant K uptake using NH_4OAc-K. In other recent investigations, NH_4OAc-K was as good an index of K availability as any other method (Schulte and Corey, 1965; Acquaye and MacLean, 1966; MacLean and

Brydon, 1971; Munn and McLean, 1975; Singh et al., 1983). Ramanathan and Nemeth (1982) obtained a significant correlation of NH_4OAc-K with K uptake from Indian soils, but its relationship with K uptake was poorer than with several other forms of extractable K. Rasnake and Thomas (1976) did not obtain a significant correlation of NH_4OAc-K with plant uptake in pot experiments with some alluvial Kentucky soils. In many pot experiments then, NH_4OAc-K has been shown to be a good index of soil K availability to plants.

Determining exchangeable K when the various forms of soil K are not at equilibrium provides a major source of variation in its measurement (Nelson, 1964). Rezk and Amer (1969) multiplied the inverse of the Gapon K selectivity coefficient (k) for each soil used to NH_4OAc-K, to correct extractable K measured at non-equilibrium conditions. They obtained slightly higher correlations of K uptake by barley seedlings with $NH_4OAc\text{-}K \cdot k^{-1}$ than with NH_4OAc-K values. Determination of $NH_4OAc\text{-}K \cdot k^{-1}$ is more laborious, though, because saturation extract and exchangeable cations must be determined to calculate k (Rezk and Amer, 1969). It is unclear if correction of NH_4OAc-K for selectivity of adsorption of K outweighs the disadvantages it presents as a routine test method.

Although the suitability of NH_4OAc-K as an index of soil K availability to plants has been heralded for several decades, Skogley and Haby (1981), in Montana, and Lopetinsky (1977), in Alberta, obtained relatively small and insignificant correlations between crop yield and NH_4OAc-K. Relationships of NH_4OAc-K with crop response variables are generally poorer in field than in pot experiments for a few reasons. In most pot experiments, K uptake was limited to Ap soil only, whereas roots in field soil can also obtain K from subsurface horizons, especially where there is little resistance to root penetration below the plow layer. Moreover, soil and growing conditions in a greenhouse can be controlled to minimize undesired limiting effects (besides soil K status) on the growth of a test crop. In field tests, however, the same degree of control is impractical. Schaff and Skogley (1982) found winter wheat response to applied K to be highly correlated with soil and site variables that were controlled by climate. The same may apply for field studies in which variations

in soil physical conditions, weather, and biological effects were encountered, but were not included as variables in regression analyses of plant yield and nutrient uptake on NH_4OAc-K.

Greater control of variations in soil and site characteristics in field tests is possible by limiting the number of, and differences in the sites selected. Singh et al. (1983) obtained a significant (0.05 level) and relatively high (r=0.874) correlation of NH_4OAc-K with yield of ryegrass at similar sites in England. Wanasuria et al. (1981) reported significant correlations (r=0.53-0.56) of NH_4OAc-K with rice yields on wetland soils at five sites, where variations in growing conditions were likely less than in a dryland setting. The correlations of NH_4OAc-K with crop responses in these two field studies were thus more comparable to those obtained in pot tests.

Another extractant which offers advantages over NH_4OAc for determining exchangeable K is molar sodium acetate (NaOAc) adjusted to pH 8.2. For soils containing appreciable quantities of clay minerals that can fix NH_4^+ and K^+ in their interlayer regions, exchangeable K determined by NaOAc extraction should be greater than that obtained by NH_4OAc. Because Na^+ is not fixed like NH_4^+ in the interlayers, Na^+ can displace more exchangeable K^+ held there (Chapman, 1965). A second advantage is that removal of carbonates in calcareous soils is not required when using NaOAc, as it is when NH_4OAc is used to measure cation exchange capacity, because of the lower solubility of carbonates at pH 8.2 than at pH 7 (Chapman, 1965). Therefore NaOAc at pH 8.2 should be considered in lieu of NH_4OAc for measuring exchangeable cations in calcareous soils, or in ones which can fix appreciable quantities of K^+ and NH_4^+.

Since slightly weathered soils can release K from non-exchangeable forms during a growing season, researchers have also been interested in the slowly or potentially available fraction of soil K extractable with medium strength acids, weak acid leaching, or other extractants. Extraction with boiling 1M HNO_3, and continuous leaching with 0.01M HCl have been used in early (see Nelson,1964) and more recent studies to extract slowly available K. Either similar (Conyers and McLean, 1969; Singh et al., 1983), or poorer (Ramanathan and Nemeth, 1982; Simonis and Nemeth, 1985) correlations of plant K uptake with HNO_3

extractable K than with NH_4OAc-K were reported. K extracted by leaching with 0.01M HCl was reported to be as good (Ramanathan and Nemeth,1982; MacLean and Brydon, 1971) or a slightly better index of K availability than NH_4OAc-K (Simonis and Nemeth, 1985). Singh et al. (1983) recently proposed a new method, extraction by HCl under reflux (HCl-reflux), as a better method than other acid extractions to assess non-exchangeable K of soils. Singh et al. (1983) found that soil K extracted by HCl-reflux was similar to NH_4OAc-K as an index of K availability to plants, but rates of K release (ug $g^{-0.5}$) gave the highest correlation with plant uptake. They suggested further testing of HCl-reflux on a wider range of crops and soils.

Sodium tetraphenylboron (NaTPB) is yet another extractant of soil non-exchangeable K which has been compared against other indices of K availability to plants. Schulte and Corey (1965) as well as Conyers and McLean (1969) obtained similar correlations of K uptake to NaTPB-K fractions or to NH_4OAc-K. Simonis and Nemeth (1985) reported that NaTPB-K was a poorer index of plant available K than several other soil extractions, including NH_4OAc-K.

Extraction of non-exchangeable K with cation exchange resins has also been tested. K extracted with an exchange resin was poorly correlated with winter wheat yield in field studies (Skogley and Haby, 1981), even though a modified procedure (resin thimble) gave a good correlation. Simonis and Nemeth (1985) used resin extraction on soils from Greece and obtained one of the three highest correlations (among 28) of K uptake with resin extractable K. Singh et al. (1983) found K extracted by Ca-saturated resin was the worst index of K availability among several extractants. Use of exchange resins has the disadvantage of being more time consuming and more complex than rapid test methods.

Except for determining K release rates by HCl-reflux, extractable non-exchangeable K seems to offer no advantage over NH_4OAc-K for assessing soil K availability. The search for alternative indices of K availibility has led others to studying soil K buffer power.

2.2.3 Soil K Buffer Curves and EUF Measurements

Soil K buffer curves should theoretically give a good indication of the K supplying power of soils, because most K uptake occurs from

the soil solution which must be replenished as plants absorb K. Quantity-intensity (Q/I) plots (buffer curves) have been used since the sixties to study the ability of soil to replenish K in solution. The activity ratio of K^+ (AR_K, as defined in 2.2.1) is taken as a measure of its activity or intensity (I) in a weak solution, which is in equilibrium with the soil solid phase. The quantity (Q) term is a measure of the amount of K^+ that exchanges with Ca^{++} or Mg^{++} in dilute solution after shaking for 1/2 hour at 25°C (Beckett and Nafady, 1967). After shaking soil with solution, the gain or loss of adsorbed K is calculated from the difference in initial and equilibrium concentrations of K. A Q/I relationship is obtained when Q is plotted on the ordinate and I on the abscissa. The slope of the linear portion of a Q/I plot for K is the potential buffering capacity (PBC). The PBC of a soil is proportional to its CEC and is a measure of its ability to maintain an intensity of K in solution (Beckett and Nafady, 1967; Munn and McLean, 1975). A measure of initially labile K (K_L) is derived from extending the linear portion of the Q/I curve to the y-axis (Beckett and Nafady, 1967). Further details on methodology of generating Q/I plots are described elsewhere (Beckett and Nafady, 1967; Parra and Torrent, 1983).

Studies have been conducted on the applicability of Q/I parameters in predicting soil K avalability to plants. Of the Q/I parameters for K, PBC and AR_K are often poorly related with plant uptake when a range of soils is used (Rasnake and Thomas, 1976; Ramanathan and Nemeth, 1982; Munn and McLean, 1975; Simonis and Nemeth, 1985). Labile K values (K_L) are more often closely related with plant uptake, probably because K_L depends on both PBC and ARk. Rasnake and Thomas (1976) in Kentucky obtained better correlation of K uptake with K_L values than with NH_4OAc-K, as did Ramanathan and Nemeth (1982) with 25 Indian soils. Others (Munn and McLean, 1975; Sinclair, 1982; Simonis and Nemeth, 1985), however, found no advantage in using K_L values over NH_4OAc-K in predicting soil K availability to plants. Evangelou et al. (1985) indicated that the binary system of K-Ca exchange does not adequately reflect the more complex cation exchange in soils. They suggested that other cations be considered in Q/I relationships to improve study of K fertility with Q/I parameters.

The length of time and labor required in producing a Q/I plot have severely restricted its adoption as a routine soil test method (Munn and McLean, 1975). With the use of a K-selective electrode, however, Parra and Torrent (1983) described how to obtain Q/I relationships more rapidly and easily than before. They showed good reproducibility and high correlations between the more rapid and older methods of deriving Q/I plots. Parra and Torrent (1983) acknowledged that obtaining Q/I relationships with the K-selective electrode requires further testing before it can be adopted as a routine method for assessing plant available K of soils.

After being first proposed in 1925, electro-ultrafiltration (EUF) has been used by West Germans since the sixties for studying the nutrient status and buffer power of soils. Proponents of EUF analysis indicate that it combines features of dialysis, eletrodialysis and ultrafiltration (for a brief discussion of each process, see Nemeth, 1979). Increasing voltages (50-400V) are applied to a soil: water suspension (1:10 at 20°C) for up to 35 min, during which desorbed ions migrate to respective platinum electrodes and get sucked through millipore filters into collection vessels (Nemeth, 1979). The quantities of nutrient ion extracted over 5 min intervals are plotted on the ordinate against time to produce a desorption curve. A detailed description of EUF procedures is given by Nemeth (1979).

Three fractions of K commonly extracted by EUF include K extractable in 10 min (EUF-K_{10}), in 35 min (EUF-K_{35}), and from 30 to 35 min (EUF-K_{30-35}). A survey of the literature reveals some controversy as to what forms of K the fractions actually measure. EUF-K_{35} apparently measures a quantity of immediately exchangeable K that is comparable to 'Q' of Q/I plots, both of which are less than 1M NH_4OAc extractable K (Nemeth, 1982; Sinclair, 1982). Although EUF-K_{10} correlates well with K concentration of the soil solution for similar soils (Nemeth, 1979), Sinclair (1982) found that EUF-K_{10} also reflects K buffer power and is therefore not a true measure of 'I' as defined by Beckett and Nafady (1967). Nemeth (1979) reported that EUF-K_{30-35} correlated with non-exchangeable K and characterized soil K reserves, but Sinclair (1982) indicated that EUF-K_{30-35} (20°C) extracted little non-exchangeable K of some Scottish soils.

Although EUF desorption curves are not equivalent to Q/I isotherms, EUF can still be used to indicate soil K availability to plants.

Suitability of EUF-K for assessing K availability has been studied in several European and Asian countries. Wanasuria et al. (1981) found K uptake by rice was more closely related to EUF-K_{35} than to NH_4OAc-K. Ramanathan and Nemeth (1982) found that EUF-K_{35} was correlated the best (among 19 indices of K availability) with K uptake by rice from various Indian soils, but not with yield. Simonis and Nemeth (1985) obtained correlations of EUF-K_{35} with both K uptake and yield of ryegrass that were among the best of 28 K availability indices of 21 soils from Greece. In Great Britain, however, Singh et al. (1983) and Sinclair (1982) found EUF-K inferior to NH_4OAc-K in correlations with K uptake and yield of ryegrass. As with other extraction methods, EUF does not appear to be a universally superior measure of soil K availability to plants.

The soil test methods considered so far can provide investigators with an indication of the intensity of K in a soil, its quantity, or a combination of both. The methods do not provide a measure of K diffusion in soil. The importance of diffusion has been demonstrated by research on soil factors affecting K supply to roots (Barber,1981), and by simulating nutrient uptake with computers.

2.2.4 Implications of Simulating Plant K Uptake

Researchers at Purdue University in Indiana have developed a mechanistic mathematical simulation model to study factors affecting plant nutrient uptake. The computer model is based on fundamental principles of nutrient uptake rather than being derived from empirical relationships in which soil extractable K is compared to its uptake by plants. Three soil parameters that describe nutrient supply to the root are considered in the model with several root growth and nutrient influx parameters (Barber, 1981). Soil parameters include the concentration of K in solution, soil K buffer power, and the diffusion coefficient of K. Silverbush and Barber (1983a) briefly describe how values of parameters are determined experimentally and used as input for the computer model.

The model has successfully predicted K uptake by corn and soybeans grown in growth chambers (r=0.87 to 0.97) when root competition is considered (Silverbush and Barber, 1983a; Barber, 1981). Study of the relative effects on predicted K uptake of changes in variables have also been conducted. This sensitivity analysis showed that root growth rate and root radius had the greatest influence on K uptake while effects of soil buffer power, concentration of K in the soil solution, and soil K diffusivity were in turn greater than effects of nutrient influx on K uptake (Silverbush and Barber, 1983b). The importance of K diffusion has spurred researchers in Montana to include it in their analyses of soil K availability (Skogley, 1985). The number of measurements required as input to simulate K uptake makes modelling impractical for rapid soil analysis (Barber, 1981). However, its use can provide insights on factors governing uptake when simpler test methods fail as indices of K availability to plants.

Test methods previously discussed only provide limited information about soil K, whereas computer modelling allows one to study effects of simultaneous soil and plant processes on nutrient uptake. Recent research in the Northern Great Plains has revealed the importance of interactions of root rot with crop responses to fertilizers (see section 2.3.4). Interaction of root diseases with root and nutrient influx parameters could be studied with computer simulation using the approach of Barber and co-workers. Because root rot can reduce yields of small grain crops, a description of the extent, effects, symptoms, causal agents, and factors affecting the disease is warranted.

2.3.0 Dryland Common Root Rot of Small Grains

2.3.1 Disease Distribution, Symptoms and Causal Agents

Common root rot of wheat and barley is a serious and widespread disease in western Canada and the Great Plains of the United States (Martens et al., 1984; Stack, 1982). The disease also has an aboveground phase (spot blotch) which is uncommon under dryland prairie conditions, but is evident under warmer, more humid conditions of eastern Canada and the U.S. (Grey and Mathre, 1984; Martens et al., 1984). Because the symptoms occur primarily below-ground in the Prairie Provinces, common root rot generally goes unnoticed by

farmers, but an annual yield loss of 10% in barley has been estimated by phytopathologists (Martens et al., 1984). Yield reductions are variable and can be as high as 100%, especially when heavy infection causes severe seedling blight (Broscious and Frank,1986). Verma et al. (1976) observed that reductions in biomass and grain yield in the field were related to severity of common root rot.

Characteristic symptoms of root rot under dryland conditions include stunting, yield reduction, and dark brown discoloration (necrosis) of lower leaf sheaths, crowns, subcrown internodes, and roots (Piening et al., 1976; Martens et al., 1984). The extent of lesions on subcrown internodes serves as the basis for rating disease intensity and severity (Ledingham et al., 1973). Severely affected plants are generally severely stunted, bear few or no tillers, and become prematurely chlorotic (Piening et al., 1976, Ledingham et al., 1973). These symptoms can be confused or related to either or both N and P deficiencies (Tewari, personal communication). Severely affected seedlings may die shortly after emergence or grow very little (Martens et al., 1984; Broscious and Frank, 1986). Grey and Mathre (1984) observed that seedlings not too severely affected by root rot in the field can recover, produce a healthy looking canopy, and not show significant yield reductions.

Several imperfect fungi are implicated in the development of common root rot, and can survive in soil along with uncounted other micro-organisms. Although Fusarium spp. are implicated in the disease complex, common root rot of wheat and barley in western Canada is primarily caused by Bipolaris sorokiniana (Piening et al., 1976; Kidambi et al., 1985). This fungus is relatively easy to identify in soil suspensions, so for the sake of simplicity and brevity, only B. sorokiniana is discussed further.

2.3.2 Description and Epidemiology of B. sorokiniana

Bipolaris sorokiniana (Sacc.in Sorok.) Shoem.syn. Helminthosporium sativum Pamm et al. [teleomorph Cochliobolus sativus (Ito & Kurib.) Drechsler ex Dastur] is a necrotrophic plant pathogen of the order Moniliales, in the class Deuteromycetes (Fungi Imperfecti). The perfect stage of the pathogen (teleomorph) is rarely observed in

nature, but develops in culture and is described (Domsch et al., 1980). Conidia (asexual spores) of B. sorokiniana are melanized, multi-septate, thick walled, ellipsoidal, straight or slightly curved, irregularly sized (6-24 X 60-150 um) structures, which are gradually tapered toward the tips like cigars (Domsch et al., 1980). Conidia are produced (sporulation) on erect conidiophores arising from mycelia and exhibit bipolar germination (from apical cells only). Sporulation begins on infected hosts as they near maturity, primarily at the crown, and can continue on crop debris as long as conditions remain favorable (Martens et al., 1984). Wind, runoff, contaminated seed, and cultivation are major agents of dispersal.

Germ tubes or other vegetative hyphae can infect host plants at the crown and subcrown regions, including roots. Infection of hosts can occur throughout the growing season, and severity of root rot progresses during the season to reach a maximum when the host matures and dries (Verma, 1982; Kidambi et al., 1985). Duczek et al. (1985) found that disease intensity and incidence were related to inoculum density in soil, but the data confirming this relationship varied greatly, even though the study was conducted in growth chambers. Environmental effects on root rot development leads to even more variability of the disease in the field (Broscious and Frank, 1986; Kidambi et al., 1985). Nevertheless, knowing which factors affect the distribution, survival, and pathogenicity of B. sorokiniana is basic for recommending good measures of control (Fradkin and Patrick, 1985).

Conidia and mycelia of the pathogen are ubiquitous in cultivated soils, and are normally concentrated within the depth of cultivation (Martens et al., 1984). Zero or minimum tillage results in relatively high conidial densities in the top few cm of soil (Duczek, 1981). Mouldboard plowing redistributes spores below the surface, but effects no measurable control of common root rot (Ledingham et al., 1960).

Infested or infected seed is another source of inoculum, but soil borne conidia and infected crop debris are the major sources under dryland conditions (Martens et al., 1984). Mycelia in crop debris can either grow and penetrate host roots or produce new conidia. Dormant conidia can remain viable in soil for years and then germinate if favorable soil conditions prevail (Chinn, 1976a; Duczek et al., 1985).

Conidial germination is stimulated by host root exudates and other substrates (Domsch et al., 1980), but competition with other organisms hinders growth of B. sorokiniana, because it has at most moderate saprophytic competitiveness (Domsch et al., 1980).

Antagonism by bacteria, actinomycetes and fungi to B. sorokiniana, and also its parasitism by bacteria and mycophagous soil amoeba (eg. Arachnula impatiens) have been observed (Domsch et al., 1980). Fradkin and Patrick (1985) observed that high soil temperature (32°C), alkalinity (pH>8.0), and high matric water potential (0-150cm suction) favored colonization of conidia by bacteria, which resulted in more rapid reduction of spore viability through lysis. Adsorption of conidia to clay minerals hinders bacterial colonization and reduces lysis of fungal spores (Fradkin and Patrick, 1985). Soil arthropods can also feed on conidia of this root pathogen (Domsch et al., 1980). Thus edaphic and climatic factors appear to control survival of B. sorokiniana, and viability of its conidia in soils. Limited experimental work has been done on the control of common root rot with meso- or micro-organisms. Studies on the effects of crop management on root rot of cereals in western Canada are more common.

2.3.3 Effects of Management and Added N and P on Root Rot

Repeated cropping with cereal crops builds up spore numbers of B. sorokiniana per unit soil mass (conidial density) with increases by crop type occurring in the order of barley > wheat = rye > oats (Chinn, 1976a; Tisdale and Ledingham, 1979; Kidambi et al., 1985). Even though oats may be the least susceptible to root rot, conidial density can still increase when they are grown (Chinn, 1976a). Decreases in number of conidia in fallowed soil have been observed, but these reductions do not reduce root rot if conidial densities remain above threshold levels needed to cause maximum incidence of disease under a given set of conditions (Chinn, 1976b; Duczek et al., 1985). Piening et al. (1983) reported similar conidial densities on fallow and stubble land without specifying cropping histories. Rotating cereals with recommended non-host crops like canola, flax, and legumes also reduces number of B. sorokiniana conidia in soil (Martens et al., 1984), but short term rotations do not always

sufficiently reduce soil inoculum to give control of root rot (Duczek et al., 1985; Kidambi et al., 1985). Reducing seeding depth lessens incidence of common root rot, but its effect on crop yield is unclear. Duczek and Piening (1982) found that yield losses corresponded to seeding depth and increased barley root rot, but Broscious and Frank (1986) found no significant effect of seeding depth on wheat yields.

Effects of fertilization with N on root rot have varied both within and among studies. Piening et al. (1969) reported that urea application reduced barley root rot, whereas NH_4NO_3 increased it. Verma et al. (1975) observed no significant effect on root rot of Manitou wheat of adding NH_4NO_3. Ledingham (1970) observed that applied NH_4NO_3 increased root rot of wheat at sites with moderate to high levels of soil N. He suggested that excessive available N predisposes plants to infection by root rot fungi. Piening et al. (1983) observed no effect of added N on root rot or yield of fallow-sown barley. They observed, however, that N application to stubble-sown barley reduced root rot and yield losses. It is difficult to attribute a specific effect of N on root rot.

An effect of added P on disease severity seems more consistent. Piening et al. (1983) found barley root rot was reduced by P added to stubble but not to fallow fields. Yield of stubble-sown barley was increased by N and P application, which they attributed to plant responses to the nutrients and reduced root rot in soil low in P (Piening et al., 1983). Verma et al. (1975) observed consistent reductions in root rot when P was added to P deficient soil, with the most benefit occurring at midseason when maximum uptake of P occurs. Garvin et al. (1981) also reported consistent reductions in root rot severity with the application of P, but effects were insignificant. The authors referred to above did not provide an explanation for the suppression of root rot obtained when P was applied to P deficient soil. Other studies have shown, however, that addition of P lessens root cell membrane permeability, thereby reducing exudation of amino acids and sugars (Ratnayake et al., 1978), which can stimulate soil micro-organisms including root rot pathogens (Domsch et al., 1980). Therefore, by adding P to P deficient soil, one can probably suppress root rot diseases by reducing host root exudates.

2.3.4 Effects of KCl on Common Root Rot

Effects of KCl on common root rot have also been reported, but not by all researchers who have studied the effects. Garvin et al. (1981) first reported a Cl^- induced reduction in root rot severity on barley at a site in southern Montana where the disease was a problem. They observed that KCl tended to give higher yields than K_2SO_4 did, but neither of the two significantly increased grain yields. Shefelbine et al. (1986) also found that Cl^- reduced common root rot of barley in southern Montana in fields with low to moderate disease incidence. Grain yield was significantly increased by applied Cl^- at only one site-year of three where reductions in root rot were recorded. Even though yield responses of barley to KCl were obtained 45% of the time by Skogley and co-workers in Montana, they observed no differences between responses to KCl and K_2SO_4, and concluded that K deficiency was the reason for the significant responses to KCl in the field (Skogley, 1985).

Research on KCl benefits to field grown wheat in South Dakota showed that a low incidence of dryland root rot was not affected by added Cl^- (Fixen et al., 1986a), although yield responses to Cl^- fertilizers on soils high in extractable K were apparently due to Cl^- alone. Fixen et al. (1986b) concluded that the benefit of Cl^- to wheat was more general than disease suppression. They suggested that a critical Cl^- content of 1.5 $g \cdot kg^{-1}$ might be better to identify Cl^- deficiency in field grown wheat than a critical value provided from solution culture studies. Timm et al. (1986), however, reported significant reductions in root rot severity from applied Cl^- at 3 of 5 study sites in North Dakota, but only one significant barley yield response to KCl was observed.

Root rot surveys at nine research sites in Alberta were conducted in 1983. Common root rot of barley was significantly reduced by Cl^- at one site, while added K reduced root rot at three sites, but the disease severity of check plots was only slight at six and moderate at another location. Hence, there is a diversity of reported effects of added KCl on the severity of root rot in the Great Plains region; it encumbers interpretation of observed effects of K^+ and/or Cl^- on the disease. Effects of K^+ and/or Cl^- on grain yield in the field

are even more difficult to identify because variable edaphic and climatic factors affect yield, and healthy plants can compensate for decreases in yield from those affected by root rot, by benefiting from reduced competition for nutrients and water (Shefelbine et al., 1986).

A direct inhibitory effect of Cl^- on root rot pathogens at usual rates of KCl application has not been reported. Objectives of recent research have been to study indirect effects of Cl^- on root rot. Incidence of root rot may be indirectly affected by effects of K^+ and Cl^- on osmoregulation of plant tissue and stomatal guard cells. A deficiency of K^+ or Cl^- in plants can cause reduced turgidity, poorer stomatal control, and related water stress (Fixen et al., 1986b; Maas, 1984), which appears to be related to root rot severity (Timm et al., 1986). More research on this relationship is required to elucidate the mechanism(s) through which disease suppression might occur (Timm et al., 1986).

Christensen and Brett (1985) reported that Cl^- inhibition of nitrification in moderately acid soils maintains a high ratio (>3:1) of NH_4^+:NO_3^- in soil, which results in more cation uptake and greater H^+ efflux from roots. This causes more of a reduction in rhizosphere pH to suppress take-all of wheat (another root disease) than if a lower NH_4^+:NO_3^- ratio occurs. Chloride inhibition of nitrification may also be implicated in affecting common root rot of cereals, but this is speculation on my part. More research of an interdisciplinary nature is needed to elucidate factors and mechanisms which control severity of dryland root rot of cereals.

2.4.0 Summary

Major areas of K deficiency for crop production in Alberta were not identified until after ca 1960. Since 1960, soil K deficiencies have been recognized, although crop responses to K fertilizers have varied. Maps produced with data from 1965 to 1969 (Cameron, 1969) and 1970 to 1983 (Kryzanowski and Laverty, 1985) show that the highest extractable K values are mainly associated with the Brown and Dark Brown soils, while the lowest occur mainly in the Black and Gray soils. An extensive area of potential K deficiency occurs in east-central Alberta, along the North Saskatchewan River basin.

Significant crop responses to added K in the sixties and seventies were observed frequently on soils containing less than 100 ug g^{-1} NH_4OAc-K (Lopetinsky, 1977; Janke, 1979), or as low as 80 ug g^{-1} NH_4OAc-K (Robertson et al.,1985). Responses to added KCl have sometimes been observed on soils with NH_4OAc-K greater than 100 ug g^{-1} in western Canada (Janke, 1979; Harapiak, 1979), and in northwestern U.S.A. (Skogley, 1985; Goos, 1984). As a result, efforts are being made in Montana to include soil K diffusion in methods of determining K availability to crops.

K in the soil solution is not as good an index as NH_4OAc-K. Use of NaOAc in lieu of NH_4OAc is suggested for measuring exchangeable K of soils that fix considerable K^+ or NH_4^+. Q/I parameters, EUF extractable K, extractable non-exchangeable K and exchange resins are generally no better than NH_4OAc-K as indices of K availability to plants. Thus no simple test method appears to be universally superior for determining soil K availability.

Computer simulation of plant K uptake is cumbersome for rapid soil analysis, but is useful for studying factors that affect K uptake. Modelling uptake might provide some insights as to why crops respond to KCl on high K soils. These responses are sometimes attributed to benefits of Cl^- to crops (Fixen et al., 1986a; Goos et al., 1986). Suggested effects of Cl^- include nutritional benefits to plants (Fixen et al., 1986b), and Cl^- induced suppression of root diseasesof small grain cereals (Beaton, 1984; Goos et al., 1987).

The primary causal agent of dryland common root rot is Bipolaris sorokiniana (Sacc. in Sorok.) Shoem.. The disease affects cereals and grasses, and generally goes unnoticed because symptoms occur mainly below ground in the prairies (Martens et al., 1984). Spores (conidia) and hyphae of the pathogen are ubiquitous in soil, are seed-borne and are stimulated by substrates like root exudates (Domsch et al., 1980). Other information about B. sorokiniana is given in section 2.3.2.

Monoculture cropping of cereals generally increases conidial densities of B. sorokiniana in soil (Chinn, 1976a; Kidambi et al., 1985). Rotation with non-host crops or summerfallow can reduce soil infestations, but short term rotations may not effect control of root rot (Chinn, 1976b; Kidambi et al. 1985). Soil inoculum density is

generally related to disease severity (Duczek et al., 1985), but climatic and edaphic factors can also affect root rot (Broscious and Frank, 1986). Excessive N can favor disease development (Ledingham, 1970), and reasonably consistent reductions in root rot have been observed when P was added to P deficient soils (Verma et al., 1975), probably because P reduced root exudates. Additions of K^+ and Cl^- have also reduced common root rot, but a Cl^- effect on the disease is not always observed. More research of an interdisciplinary nature is needed to clarify how root rot and crop plants are affected by soil and fertilizer macronutrients.

3. MATERIALS AND METHODS

3.1 Description of Sites, Soil Collection and Analysis

Samples of surface soil for this study were selected from former and existing research sites that were used to assess responses of barley to applied KCl in central and east-central Alberta (Table 1). Sites 1 to 3 were established by Robertson and co-workers (Robertson et al., 1985), while sites 4 and 5 were selected from fertility work conducted by the late D. R. Walker near Lacombe. Soil at site 6 was selected as a "control" because crops grown there showed no sign of response to added KCl (Heapy et al., 1976; Webster et al., 1976). Little or no barley response to KCl was observed at site 1 in field experiments, while response at sites 2 to 5 has been observed (Robertson et al., 1985). Sites 1 to 5 are imperfectly to poorly drained, while site 6 is moderately well drained.

Samples from sites 1 to 3 were collected from the surface 10 cm of soil from areas adjacent to check plots, after removing most of the crop debris. Surface samples from sites 4 to 6 were taken from the vicinity of former plots. Samples were air dried, passed through a 5 mm sieve, and then mixed in an end-over-end mixer. Duplicate sets of subsamples were taken from bulk soils for analysis before setting up a greenhouse experiment. Field capacities (FC) of sieved samples were determined by adding enough water to saturate half the length of soil placed in vertical tubes, and waiting 48 h before measuring its gravimetric moisture content. Inorganic carbon was approximated gravimetrically based on its dissolution in HCl (Allison and Moodie, 1965). Total C was measured by combustion in an induction furnace (McKeague, 1978) and organic C was calculated as the difference between total and inorganic C. Exchangeable K and CEC of the samples were measured by the NH_4OAc and NaOAc methods of displacing exchangeable cations, as outlined by Chapman (1965). Concentrations of K^+ and Na^+ in the extracts were measured by atomic absorption spectroscopy (AAS; method 3.31, McKeague, 1978); NH_4^+ content was determined using an ammonium electrode. The second set of subsamples was sent to the Agricultural Soils and Animal Nutrition Lab (ASANL) to assess quantities of macronutrients required, except for K, to raise the contents of nutrients in the soils to a common fertility level.

Table 1. Sites, owners, textures and parent materials of soils

Site	LOCATION	Land Owner	Soil*	Parent material
1	SE 21-61-9-W4	D. Bacque	O.DG;GL.DG	mainly till
2	NW 14-61-9-W4	J. White	D.GL;GLD.GL	fluvial (1 m) over till
3	NW 9-62-2-W5	W. Nanninga	R.HG	fluvial (1 m) over till
4	NE 1-44-25-W4	R. McKelvie	R.HG	fluvial (> 1 m thick)
5	NW 11-41-28-W4	R. Prins	GL.BL	fluvial (> 1 m thick)
6	NE 24-40-27-W4	Ag.Can. Stn.	O.BL	fluviolacustrine

* abbrev. as per CSSC (1978); sites 1-3 described by J.A. Robertson, Univ. of Alta., and W. Pettapiece, Ag. Can.; sites 4-6 by G. Coen, Ag. Can. Soil Survey, Edmonton

3.2 Greenhouse Experiment

For all crops, closed bottom pots 18 cm in diameter and 14 cm deep were filled with the test soils to within 2 cm from the top rim. A similar volume (2.5 L) but different masses of the various air dry soils were potted, because of differences in bulk density among them. Bulk densities of the potted soils were calculated using oven dry masses and an approximate pot volume. Soil from each pot was spread in a layer 1 to 2 cm thick and sprayed with an appropriate solution of fertilizer N (NH_4NO_3), K (KCl) and S ($MgSO_4$), was manually mixed and repotted. N, S and Mg were applied at 50, 10 and 7.5 ug g^{-1}, respectively. Fertilizer P (Na_2HPO_4) at 25 ug g^{-1} was applied in a circular band about 5 cm deep. Initial treatments consisted of a control (no KCl added), intermediate or mid (300 ug g^{-1} K), and high (600 ug g^{-1}) rates of added K as KCl. The pots containing KCl were cropped without measuring exchangeable K after the soil was treated. Soil by treatment combinations were randomized and replicated thrice.

Untreated Klondike barley (Hordeum vulgare) was seeded about 2 cm deep and distilled water was added to raise soil moisture content near field capacity. The barley was thinned to 6 plants per pot at the 3 to 5 leaf stage. Distilled water was regularly added to the pots to keep soil moisture between 60 to 100% FC. An additional 50 ug g^{-1} of N was added to all pots 3 to 4 weeks after seeding. Supplemental

light was provided to maintain a 15 h daily photoperiod. Temperature in the greenhouse was monitored daily since it fluctuated with ambient air temperature and cloud cover. The crop was periodically examined for signs of nutrient deficiencies and/or leaf diseases.

Top growth was harvested when most of the plants had reached the stage 10.1 on the Feekes scale (Large, 1954), except crop 3, which was harvested earlier because of Christmas. The barley was dried at 65 to 70°C for 48 h in separate paper bags and weighed. Leaf and stem material was finely ground, dry ashed, then dissolved in HCl following the procedure outlined by Isaac and Kerber (1971). Interpretations of plant nutrient contents were made based on critical levels proposed by the Manitoba Provincial Soil Testing Laboratory (MPSTL, 1982).

Subcrown internodes were excavated, cleaned, and examined for evidence of root diseases. Soil thereby removed was returned to the appropriate pots. Symptoms of root rot on subcrown internodes of barley were rated on a scale of 0 to 3, based on classes described by Ledingham et al. (1973). The mean value of root rot of the six internodes from each pot was recorded. A portion of the remaining root mass was separated from the soil using a 5 mm screen, but the fine roots were not separated. Soil from each pot was spread to air dry and then sampled. Exchangeable K of the samples was extracted with NaOAc adjusted to pH 7 (3.34; McKeague, 1978). Extracts were analyzed by AAS after appropriate dilutions were prepared.

All soil by treatment combinations were recropped (crop 2) with Klondike barley without adding more KCl. Various rates of N (0 to 50 ug g^{-1}) were added to the soils based on mineral N content of samples taken after the first crop. Rates and methods of application of P and S fertilizer were the same as for crop 1. Soils from replicates (reps) 2 and 3 for sites 2 and 3 were fumigated with chloroform before seeding, as a preliminary step in meeting objective number 3 (Introduction). The fumigation technique is described below. Monitoring and harvesting the second crop as well as analyzing soil and plant samples was done as specified for crop 1.

Soil in all pots was fumigated with chloroform to reduce the effect of root rot on yield before seeding the third crop of barley. All soil was moistened to field capacity and allowed to sit for a few

days at room temperature to promote growth of the root pathogens prior to fumigating. Chloroform (40 ml) was added to the bottom of a large desiccator and vaporized under vacuum to effect fumigation of soil retained above the chloroform by a perforated ceramic plate and a piece of cheesecloth. Soil from each pot was fumigated separately for about 20 h. Chloroform was then drawn out of treated soil by repeatedly evacuating (12 times) the desiccator. The soil was spread to air dry, was sampled, and then repotted.

Rates of P and S added at seeding time were 20 and 5 ug g^{-1}, respectively. Additional KCl at K rates of 200 and 400 ug g^{-1} was added to pots that had initially received K at 300 and 600 ug g^{-1}, respectively, while no KCl was added to control pots. Experimental design was the same as for crop 1. More N was applied at 40 ug g^{-1} 2 weeks after seeding Klondike barley, and at 30 ug g^{-1} 3 weeks later with appropriate volumes of distilled water. Crop growth and greenhouse conditions were monitored. The barley was harvested when most of the plants had developed past stage 6 (Feekes scale). Analyses on harvested portions and soil samples were performed as was described for the first crop.

For the fourth crop, Empress barley was seeded without further fumigation of all soils. Rates of N, P and S added were 40, 30 and 20 ug g^{-1}, respectively. Another 200 and 400 ug g^{-1} K was added to pots initially treated (crop 1) with K at 300 and 600 ug g^{-1}, respectively. More N (40 ug g^{-1}) was added 3 and 6 weeks after seeding. Greenhouse conditions were monitored once again. Crop 4 was harvested when stage 10.1 on the Feekes scale was reached. Analyses of soil and barley samples were repeated as described earlier.

3.3 Soil Incubation Experiment

A separate pot experiment of fumigated and non-fumigated (control) soils was designed to meet objective # 5. Soils from sites 2, 3, 4 and 6 were selected to represent a range in root rot severity from severe to clean. Each of the soils was scooped into 6 closed bottom pots, moistened to field capacity, and left to sit at room temperature for 3 days. Then 3 pots of each soil were fumigated with chloroform in large desiccators in the same manner specified in section 3.2. The

remaining 12 pots (controls) were left to sit at room temperature during the fumigation treatment (1 day). All soils were then spread to air dry, were sampled, and then repotted.

An incubation period began when these potted soils were moistened to field capacity. All pots were incubated at 22°C for 4 weeks in the dark, and were periodically watered. Soil samples were taken with cork borers 2 and 4 weeks after the start of the incubation period. Exchangeable K of the samples was extracted with NaOAc adjusted to a pH of 7 (method 3.34; McKeague, 1978). Mineral N was extracted with 2M KCl (method 4.35; McKeague, 1978), and measured colorimetrically by auto-analyzer. Conidial densities of Bipolaris sorokiniana in both fumigated and control soils were estimated by the modified oil-water emulsion extraction technique described by Duczek (1981). The viability of spores was estimated by examining them after they had incubated in potato dextrose agar for 16 to 20 h at 20°C in an incubator.

3.4 Statistical Analyses

Barley yield and K uptake data for each crop were subjected to analysis of variance using the MANOVA procedure of SPSS[x1]. Data were analyzed for a randomized complete block design in which 3 blocks (reps) consisted of all possible soil by treatment combinations (6x3). Analysis of variance of root rot ratings was performed using both MANOVA and the MGLH program of SYSTAT[2] to compare output. The Tukey multiple comparison procedure was used to determine if root rot means differed among KCl treatments. The data were verified for goodness of fit to normality by comparing Kolmogorov-Smirnov one sample statistics to Lilliefors test values (Zar, 1984). Homogeneity of variance of the data was not tested because test procedures are highly sensitive to anormality, and are not recommended (Zar, 1984).

Plots of yield and K uptake versus either exchangeable K or root rot were checked for unusual trends in the barley data. Stepwise multiple regression of barley yield and K uptake on exchangeable K and root rot scores was performed. Residuals from regression were used in various tests recommended by Norusis (1983) to check for violations of

1 Registered trademark of SPSS Inc., Chicago, IL
2 Registered trademark of SYSTAT, Inc. Evanston, IL

assumptions, namely independence of error, homogeneity of variances, linearity, and normality. Normality of residuals was also checked by comparing Kolmogorov-Smirnov test statistics to a table of Lilliefors test values.

Analysis of variance (MANOVA) was performed on exchangeable K and conidial density data from the incubation experiment. Experimental design specified in the analysis was a randomized complete block 4x2 factorial, in which blocks were time of sampling in the experiment. The fit of the data with the normal distribution was checked as specified above. Treatment and soil means were compared using a Tukey multiple comparison procedure.

4. RESULTS AND DISCUSSION

4.1 Chemical and Physical Characterization of Soils.

Selected properties of soil samples used in the greenhouse study are given in Table 2. All six soils are relatively coarse textured, with soils 2 to 6 having developed on parent materials mainly of fluvial origin (Table 1). Sample 5 had the highest bulk density (Db) among the potted soils (Table 2), because it contained the most sand and the least organic carbon. Sample 4 contained the most organic C and carbonates, and thus had the lowest Db. The latter sample was taken from a Humic Gleysol that is probably affected by groundwater discharge. Mottling was observed within 50 cm of the surface at both sites 3 and 4, which indicated poor drainage. Sample 3 contained more soluble salts and less carbonates than sample 4. Soils 1, 2 and 5 were imperfectly drained, with distinct to prominent mottling being found below 50 cm. Sample 1 contained relatively high organic C, probably because the area it came from had a history of heavy manuring (J.A. Robertson, personal communication). Sample 5 contained high extractable K because it also was manured. Electrical conductivity (E.C.) and pH values of the soils, though varying considerably, were not deemed to present serious limitations to barley growth.

Soil organic C contents of all six samples were highly correlated (0.01 level) to cation exchange capacity (CEC), field capacity (FC), and Db of the soils (r=0.94, 0.94 and -0.98, respectively). CEC, FC and Db were not significantly related (0.05 level) to clay content of the samples (r=0.75, 0.54 and -0.66, respectively), probably because of their relatively low clay contents. Thus, differences in CEC, FC, and Db among these soils are mainly related to organic matter content.

Exchangeable K was not significantly correlated (0.10 level) with either organic carbon or clay content (r=-0.71 & -0.56, respectively). No significant correlation of exchangeable K to CEC of soil clays was obtained from data presented by MacLean and Brydon (1971). They did find, however, that amounts of K fixation and release were related to types of clay minerals in several Canadian soils, but the relationship was obscured by an increase in the proportion of interstratified clays (MacLean and Brydon, 1971). Song et al. (1984) observed an increase in vermiculitic clay content and a decrease of exchangeable K in samples

Table 2. Some physical and chemical properties of study samples before cropping

Sample Site #	% particle size[1] sand	silt	clay	texture	Db Mg m^{-3}	FC %	Inorg. C %	Org. C[2] %	pH[3]	E.C.[3] dS m^{-1}	CEC[4] (+) cmol kg^{-1}	Exch-K (+) mmol kg^{-1}
1	44	37	19	L	1.1	35	0.0	6.5	6.4	0.6	50	7.11
2	44	46	10	L-SL	1.1	32	0.0	4.9	6.8	0.7	44	2.46
3	36	41	23	L	1.1	40	0.1	6.6	7.4	1.1	59	1.98
4	50	34	16	L	0.9	51	3.7	8.1	7.9	0.9	60	1.50
5	70	24	6	SL	1.3	28	0.0	3.7	5.8	0.3	28	12.53
6	48	37	15	L	1.2	33	0.0	4.7	5.7	0.2	40	7.30

1. hydrometer method (McKeague, 1978)
2. Org. C = total C (method 3.61, ibid) - inorg. C
3. measured in 1:2, soil:water (ibid)
4. NaOAc method (see section 3.1)

from an Eluviated Eutric Brunisol to a Rego Humic Gleysol of a catena in Saskatchewan. Al-Kanani et al. (1984) concluded that significant quantities of clay-sized feldspar along with phyllosilicates of 5 Quebec soils contributed to their K supply characteristics. Hence the clay mineralogy and history of manuring (sites 1 and 5) were likely more important than clay content in affecting exchangeable K of the soils used here, but the mineralogy of the samples was not determined.

Correlations of initial soil exchangeable K (Table 3), extracted with NaOAc and NH_4OAc, to barley K uptake (crop 1) did not differ (r=0.918 and 0.919, respectively). There was thus no advantage in using one extractant over the other in assessing soil K availability to barley with the six soils used here. Chapman (1965), however, indicated that NaOAc extraction might be more appropriate for soils which have high K^+ or NH_4^+ fixation capacities. Quantities of K extracted by the two methods could not be directly compared because of differences in extraction methodology. The number of samples used in this study was also inadequate to allow one to accurately compare the effectiveness of the methods.

4.2 Observations and Analysis Of Barley Crop No. 1

Results for each crop were analyzed separately because length of and conditions during the growing period varied appreciably from one crop to another. Observations and summaries of analyses are therefore presented accordingly.

Diurnal temperature in the greenhouse compartment for the first crop fluctuated by as much as 20°C on sunny days because of an inadequate cooling system. The maximum daily temperature during the fifth week reached the 30 to 38°C range on 5 days during week one in May, which caused the onset of wilting on some pots of the control (no KCl), despite regular watering. Average minimum temperature was about 15°C, but was not lower than 12°C, and hence varied less than the maxima. Low temperature stress was probably avoided.

Stress symptoms of barley were first observed only 2 weeks after emergence. Stunting (reduced growth) was apparent 2, 2.5 and 3.5 weeks after emergence on all three K treatments of soils 3, 2 and 1, respectively. Marginal chlorosis followed by necrosis was observed on

Table 3. Exchangeable soil K measured before and after each crop, along with barley K uptake, for crops 1 and 2

Soil No.	Fert. KCl Treatment	Exchangeable K (mg/kg) NH OAc	Exchangeable K (mg/kg) NaOAc extractable		Barley uptake of K (mg/pot)	
		Initial	Initial	Crop 1	Crop 2	Crop 1	Crop 2
1	Nil added	220.1	278.3	189.6	160.4	224.1	206.5
1	Mid rate			341.4	228.9	286.1	399.4
1	High rate			497.8	359.7	369.1	447.0
2	Nil added	77.2	96.2	92.0	57.2	43.1	222.8
2	Mid rate			173.2	84.8	175.2	423.5
2	High rate			284.2	155.8	258.7	560.7
3	Nil added	57.8	77.4	83.4	51.6	19.2	214.4
3	Mid rate			184.0	81.1	83.0	526.3
3	High rate			297.4	123.7	102.8	623.4
4	Nil added	42.0	58.8	60.7	60.1	64.1	71.0
4	Mid rate			74.7	64.3	498.9	133.3
4	High rate			139.7	76.5	671.4	337.4
5	Nil added	470.3	490.0	325.5	201.9	597.2	514.1
5	Mid rate			446.7	289.2	977.6	564.1
5	High rate			594.0	452.7	1061.7	727.5
6	Nil added	229.9	285.3	151.2	110.6	531.5	331.3
6	Mid rate			256.5	161.6	783.0	506.1
6	High rate			457.0	289.3	896.5	638.4

barley from control pots of soils 2 and 3 after stunting developed. Older barley leaves on soil 3 developed interveinal chlorosis 3 weeks after emergence, with necrosis setting in 1 week thereafter. Symptoms were more severe for the control treatment. Some stunting of barley on the control of soil 4 was observed after 4 weeks, and chlorosis of older leaves was noted about 1 week later. Stunting grew worse over the growth period (7 weeks), and was associated with a lack of tillering on sample 3 by harvest time. Barley on soils 5 and 6 exhibited no obvious stress symptoms throughout the experiment, and produced 4 to 6 tillers per plant. Symptoms of barley scald and net blotch diseases were limited to a few leaves from sample 4 only.

Low K content in barley (MPSTL guidelines, 1982) was noted for all three replicates (reps) from control pots of soil 4, which contained the least exchangeable K (Table 3). Marginal K levels were observed in barley samples from control pots of soils 2 and 3, which had the next two lowest levels of exchangeable K. K contents in barley from soils 1, 5 and 6 for all treatments, and soils 2 to 4 for the two KCl treatments were sufficient for normal development. N and possibly P deficiency symptoms appeared on the more vigorously growing stands 1 week before harvest.

Crop 1 was harvested 7 weeks after seeding. Barley yields were highly variable among the six soils at harvest (Figure 1). Reduction in yield resulted, in large measure, from lack of tillering, but also from reduced height and smaller leaves (stunting). Mean yield from the control pots of soil 5 was 11 times greater than that from soil 3 due to lack of tillering and stunting. Additions of KCl increased yields relative to K controls for each soil (Figure 1), but the KCl failed to increase yields on soils 1, 2 and 3 anywhere near the levels obtained on soils 5 and 6. Mean yields from soil 5 were still nine times greater than those from soil 3 even with added KCl.

Barley yield and K uptake differed significantly among soils, K treatments and soil by treatment interaction (Table 4). Variability among soils accounted for 91% and 78% of the total variabilities (calculated from ANOVA sums of squares) in yield and K uptake, respectively. The KCl thus had little effect in reducing variability in yield and K uptake among the six soils. A significant interaction

Figure 1. Mean dry matter yields (3 reps) of barley from crop 1 for all combinations of KCl treatments and surface Ap samples

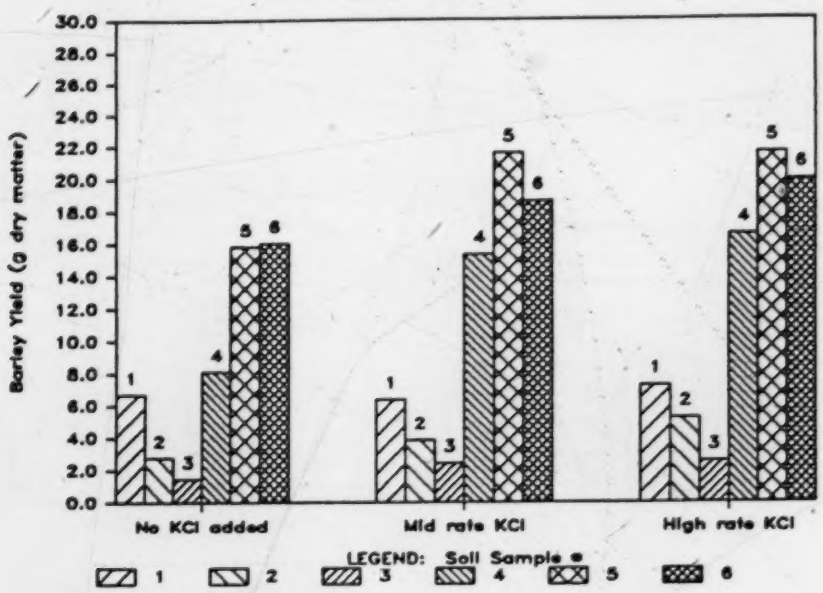


Figure 2. Mean root rot severities (3 reps) on barley of crop 1 for all combinations of KCl treatments and surface Ap samples

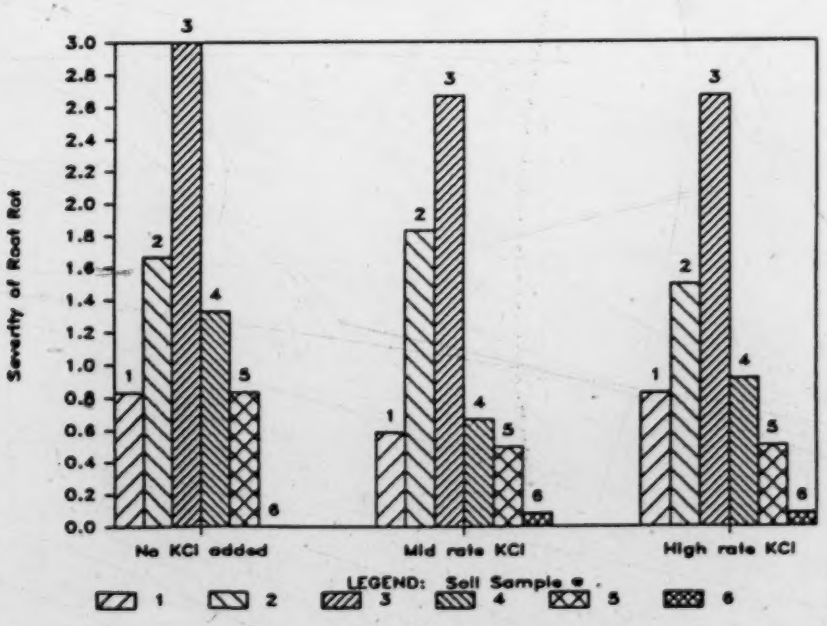


Table 4. Analysis of variance of data for crop 1

		Barley K uptake			Barley yield			Root rot scores		
Factor	DF	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F
Reps	2	441	0.32	.728	0.15	0.5	.622	0.0556	0.92	.409
Soils	5	933961	677.83	.000	504.18	1598.3	.000	8.2722	136.83	.000
K-Trmt	2	466877	338.84	.000	69.84	221.4	.000	0.2639	4.36	.021
S by T	10	34486	25.03	.000	9.32	29.5	.000	0.0903	1.49	.185
Error	34	1378			0.315			0.0605		

Table 5. Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 1 (control pots only)

	Mean barley K uptake				Mean barley yield			
Independ. Variable	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r
Exchang. K	1.112	0.166	0.866	.000	1.664 E-2	5.504 E-3	0.615	.009
Root rot	-75.764	26.992	-0.589	.013	-3.313	0.897	-0.690	.002

of soils with K treatments reflects the variability of barley response to KCl among the soils. Comparisons of means were not performed because of the inappropriateness of this analysis procedure for experimental designs that consist of combinations of more than two factors, each at two or more levels, especially if the main effects interact (Peterson, 1977). The F tests (Table 4) were deemed valid even though 44% of the distributions of soil and treatment means were significantly anormal. The same conclusions were drawn from an ANOVA of the log transformed data, which exemplifies the robustness (ability to yield valid conclusions with or without deviations from underlying assumptions) of the ANOVA procedure.

In an effort to explain the considerable differences in barley growth, leaf and soil samples from soils 2, 3 and 6 were analyzed by ASANL. Marginal concentrations of B, Mn and Zn were found in barley from soil 3, which might have been caused by the poor condition of the barley, since no nutrient deficiencies were detected by DPTA extraction of the soils. Marginal N was observed in whole plants from soil sample 6. Since a nutrient deficiency did not explain the variability in yield within the K treatments, the roots from all pots were examined as advised by a plant pathologist.

Root rot symptoms on subcrown internodes and barley roots (Figure 2) varied from clean (rating of 0) for soil 6, to severe (rating of 3) for soil 3. The rooting system from the latter soil was very limited compared to the former, with most subcrown internodes from soil 3 being completely brown (dry rot), rather than a healthy white. Differences in root rot severity among both soils and KCl treatments were statistically significant (Table 4), but soils explained 92% of the variation in root rot. Although two distributions of means were anormal among six soil and three treatment means, the robustness of the ANOVA procedure was relied on to provide a valid analysis of the root rot data. Discussion of the effect of KCl on root rot severity will follow in section 4.9.

Barley root rot in the greenhouse was more severe than that reported in field trials for the same sites (Robertson et al., 1985). Restricting rooting volume in pots to Ap soil from the top 10 cm may partly explain why root rot was more severe in the greenhouse, because

the major pathogen is found mostly in the top 15 cm of cultivated soil (Duczek, 1981). More favorable soil moisture and temperature in the greenhouse than in the field for infection of roots may also partly explain the difference in root rot severity between the two settings.

Since plant yield and K uptake are functionally related to soil exchangeable K, multiple regression was performed to examine the relationships. Regression of either barley yield or K uptake on soil exchangeable K is reported more often for soil K measured before than after cropping. Since exchangeable K was determined for only control pots before cropping, regressions in this study were done on data from the control treatment (no KCl added). Data for the regressions were not transformed because analyses of residuals indicated that the assumptions for regression were not seriously violated.

Stepwise multiple regression showed highly significant effects of both soil exchangeable K and root rot on both barley yield and K uptake (Table 5). The slopes (B coef.) of the regression lines show that yield and K uptake were positively correlated (partial 'r' coef.) to exchangeable K, as is frequently reported in the literature, and negatively correlated to severity of root rot. A comparison of figures 1 and 2 illustrates the inverse relationship between root rot and barley yield. Degree of stunting and reduction in tillering corresponded to incidence of root rot, which agrees with observations made by Ledingham et al. (1973). Reductions of dry matter produced in the greenhouse should not be equated with reductions in the field, however, because other growth factors can mask the effect of root rot on yield in the field. Tinline and Ledingham (1979) reported that correlations of disease to yield losses in field trials are highly variable and often insignificant.

A comparison of K fertility among the six soils with respect to other soil properties was not attempted with crop 1 data, because of the significant effect of root rot on barley K uptake. A crop that is not subject to common root rot could have been used in subsequent crops to avoid the disease problem, and allow one to study K fertility status. Alternatively, barley could still be grown if the root rot pathogen(s) were effectively controlled by a method of sterilization. The latter approach was chosen and the study objectives were revised

to allow further cropping with barley. Control of root rot in samples 2 and 3 was attempted by fumigating these soils with chloroform before seeding the second crop.

4.3 Observations and Analysis Of Barley Crop No. 2

Temperature in the greenhouse for the second crop fluctuated by only 8°C on sunny days because of more efficient artificial cooling for this crop than for the first. The maximum daily temperature reached was 26°C during the second week of July, or 1 week after seeding, while mean minimum temperature was 18°C. Minimum and maximum temperature stresses were thus probably avoided. Moisture stress was not observed during the growth period.

Crop emergence was fairly uniform with a difference of only 1 day between emergence of the first and last coleoptiles. Many brown spots, identified as physiological spotting, appeared at random among pots 10 days after emergence. The cause of the spotting remains unknown. An insecticidal soap was used to control an outbreak of thrips in the greenhouse 2 weeks after emergence. An inadvertent application at 2.5 times the usual rate of insecticide resulted in leaf deformation where the spray had accumulated on leaf tissue next to the stem, and where new leaves were emerging. The damage among the pots was variable, but not enough to warrant termination of the experiment.

Stress symptoms on barley were first observed about 2 weeks after emergence on soils 2 and 3, with the non-fumigated rep showing much more stunting than the fumigated reps for both soils. Interveinal chlorosis of leaves started showing a few days later on the non-fumigated pots of soil 3, while the barley on the fumigated pots of the same soil appeared healthy except for some marginal chlorosis. This chlorosis or scorching developed over the growth period on the fumigated pots of soils 2 and 3, but the plants tillered well compared to the barley on the non-fumigated pots. Some tip scorch was apparent one month after emergence on many pots. Barley on the K control of soil 4 showed much stunting compared to the pot which received the initial high rate of KCl (added before crop 1).

Barley crop 2 was harvested with most of it having reached stages 10.0 to 10.1 on the Feekes scale about 6 weeks after seeding, or 5

weeks after emergence. The degree of stunting was the greatest on the non-fumigated pots of soil 3 followed by non-fumigated pots of soil 2, as was observed for crop 1. Degree of stunting again corresponded to reduction in tillering. Tissue samples selected from barley on soils 2, 3, 5 and 6, and analyzed by the ASANL, showed lower P, Mn and Zn concentrations from the non-fumigated than fumigated pots of soil 3. Lower nutrient contents may result from poorer nutrient uptake by diseased plants, since root rot negatively affects root number, size and functions (Agrios, 1978).

Because fumigation of the first two of three reps of soils 2 and 3 introduced another source of variation in the overall data, the third rep was omitted from the calculation of mean barley yields and root rot severity for this crop. Variability in barley yields (Figure 3) among soils appears to be less than variability in root rot severity (Figure 4). A reduction in the variability in barley yields and root rot from crop 1 to crop 2, which could not be attributed solely to the fumigation of soils 2 and 3, is discernible by comparing figures 1 and 2 to figures 3 and 4. Differences in previous barley K uptake and increased root rot in the other soils, particularly in sample 6, may have also contributed to reductions in the above variability.

Low to marginal K levels were observed in barley from control pots of soil 4, which contained the least exchangeable K after crop 1 (Table 3). Marginal to near marginal plant K contents were obtained on soil 4 which received the initial mid rate (300 ug g^{-1}) of K, and which contained the second lowest level of exchangeable K (Table 3). Marginal to near marginal K concentrations were also observed in barley from control pots of soils 2 and 3, which had the next two lowest levels of exchangeable K after crop 1 (Table 3). K contents in barley from soils 1, 5 and 6 for all treatments, and soils 2 and 3 for the two rates of added K were sufficient. Marginal P content was reported for barley from rep 2 of soil 3. Plant K contents were comparable to those observed for the first crop, except for that from soil 4 with the mid rate of added KCl.

Mid and high rates of KCl added before cropping increased barley yields (Figure 3) and K uptake (Table 3) relative to K controls except for yield at the high rate on soil 2. Variation among the treatments,

Figure 3. Mean dry matter yields (3 reps) of barley from crop 2 for all combinations of KCl treatments and surface Ap samples

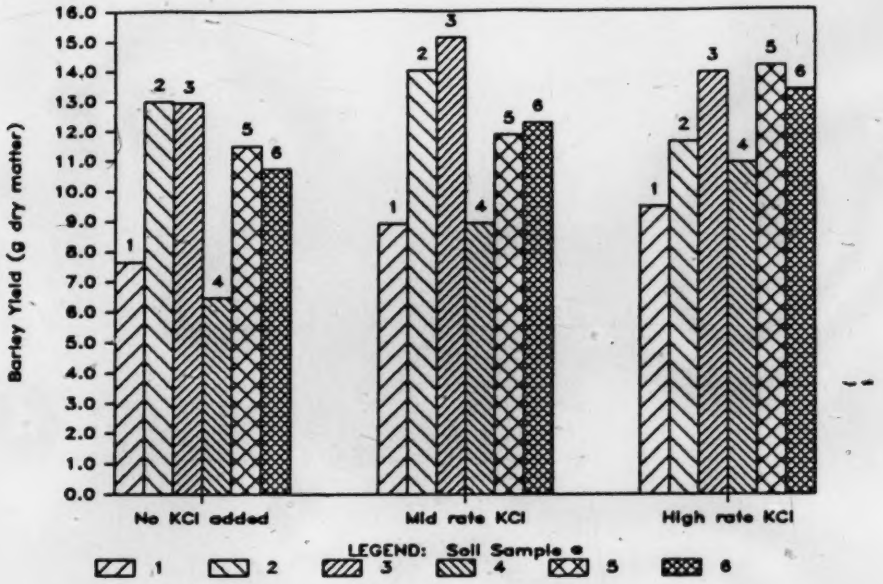
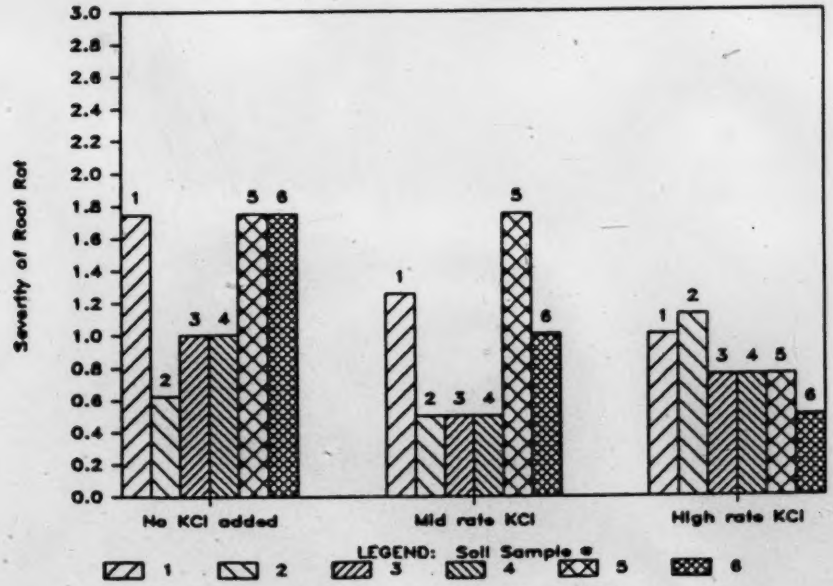


Figure 4. Mean root rot severities (3 reps) on barley of crop 2 for all combinations of KCl treatments and surface Ap samples



however, accounted for only 10% and 39% of the variabilities in yield and K uptake, respectively, whereas variation among soils accounted for 44% and 62% of the same variabilities. Significant differences existed among soil and K treatment means for barley yield and K uptake (Table 6). The interaction between soils and K treatments was not significant here as it was for the first crop. The ANOVA was deemed valid because only one of the 18 distributions of means for the six soils and three treatments was anormal ($0.05 < P < 0.10$). Comparisons of means were not done for reasons given in section 4.2.

Root rot symptoms on subcrown internodes of barley varied (overall data) from very slight to slight (<1) for most soils which received KCl, to moderate (2) for the control pots of soils 1, 5 and 6 (Figure 4). The rooting systems from the non-fumigated pots of soils 2 and 3 had moderate root rot, and were developed much less than roots from the fumigated pots of the same soils which showed only slight root rot. Differences in root rot severity among soils and KCl treatments were significant (0.05 level; Table 6), as was observed for crop 1. The ANOVA of root rot data was considered valid because distributions of means for soils and treatments were not anormal, based on the Kolmogorov-Smirnov test for normality. Interpretation of the effect of KCl on root rot is given in section 4.9.

Multiple regression reflected a highly significant effect of soil exchangeable K on uptake (Table 7), which was not affected significantly by root rot. The effect of exchangeable K on barley yield was significant at 0.05, whereas that of root rot was only significant at 0.10. The slope (B coef.) of the regressions indicate that yield and K uptake were positively correlated to exchangeable K, as reported elsewhere, and that yield was negatively correlated to severity of root rot. By comparing figures 3 and 4, this inverse relationship between root rot and barley yield can be observed. Degree of stunting and reduction in tillering again corresponded to severity of root rot. Data for the regressions only included control treatments and were not transformed, the reasons having been given in section 4.2.

Table 6. Analysis of variance of data for crop 2

		Barley K uptake			Barley yield			Root rot scores		
Factor	DF	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F
Reps	1	11552	1.38	.256	5.881	2.78	.114	0.1110	0.909	.459
Soils	5	113860	13.60	.000	29.668	14.04	.000	0.4778	3.912	.018
K-Trmt	2	249317	29.77	.000	11.721	5.55	.014	0.9080	7.435	.004
S by T	10	6218	0.74	.678	2.584	1.22	.344	0.2622	2.147	.086
Error	17	8375			2.113			0.1221		

Table 7. Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 2 (control pots only)

	Mean barley K uptake				Mean barley yield			
Independ. Variable	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r
Exchang. K	1.452	0.207	0.869	.000	1.986 E-2	9.428 E-3	0.478	.052
Root rot	n.d.	n.d.	-0.288	.263	-2.695	1.504	-0.420	.093

n.d. not determined

4.4 Observations and Analysis Of Barley Crop No. 3

Temperature in the greenhouse for this crop fluctuated at most by 8°C on sunny days in November, and even less in December, when supplemental light was needed the most to maintain a 15h photoperiod. The maximum daily temperature reached was 22°C at the end of week 1, while a mean minimum temperature of 12°C was recorded. Minimum and maximum temperature stresses on the barley were probably avoided. Moisture stress was avoided by frequent watering of all pots.

All soils were fumigated prior to seeding, as described in section 3.2, to try to control common root rot and limit its effect on barley. Another 200 and 400 ug g^{-1} K were added to the initial mid and high KCl treatments, respectively, because K uptake of the first two crops from soils 4, 5 and 6 had depleted the K initially applied. Emergence of the third crop was quite uniform with less than a day between the first and last coleoptiles to emerge within a rep. Growth of the third crop was slower than the first two because of lower mean temperature and lower light intensity over the growth period.

Necrosis of leaf tips was observed on all pots one month after emergence, and was not related to any other observable features. The barley on the control treatment of soil 6, rep 1, remained severely stunted for a month before it recovered, even though root rot was only slight. Some leaves on the controls of soils 5 and 6 of the other reps showed an unusual white interveinal streaking which could not be identified as a nutrient deficiency, according to analyses of striped and healthy leaf tissue by the ASANL, and was not symptomatic of a common disease of barley. For lack of a better explanation, some unknown phytotoxic product of chloroform fumigation is thought to have caused the white stripes, because the symptom was observed for this crop only on barley that showed some stunting.

One datum, that for rep 1 of soil 6 without KCl, was not included in deriving Figure 5, because of the severely stunted growth noted above. No other problem symptoms were noted apart from general stunting of growth that developed by harvest time on control pots of soils 2 and 4, with the most stunting showing on soil 4. The stunted growth corresponded to two of the lowest exchangeable K values after crop 2 (Table 3). By comparing Figures 1 and 3 to 5, one can see that

Figure 5. Mean dry matter yields (3 reps) of barley from crop 3 for all combinations of KCl treatments and surface Ap samples

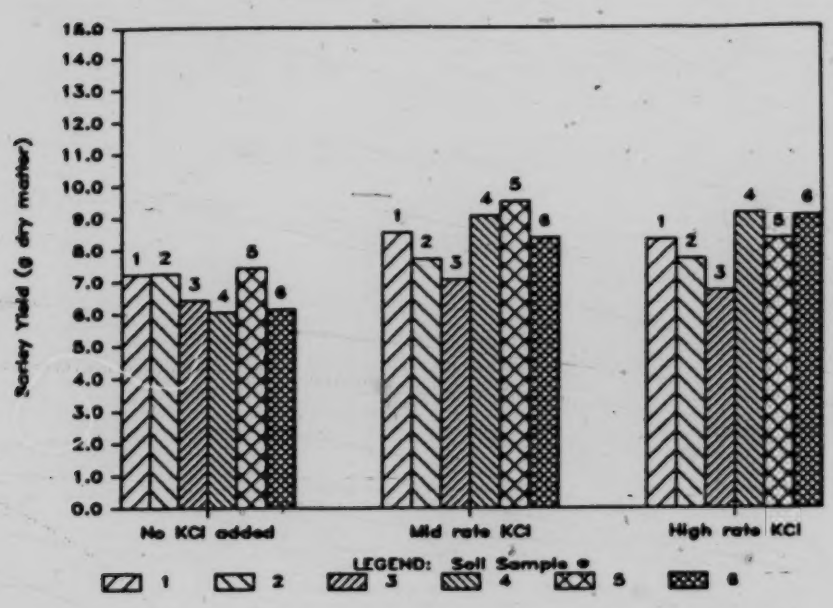


Figure 6. Mean root rot severities (3 reps) on barley of crop 3 for all combinations of KCl treatments and surface Ap samples

differences in growth between control pots and the two KCl treatments were less than those obtained for crops 1 and 2, with the least response to KCl being noted for soil 3. By comparing Figures 1 and 3 to 5, one can also see that variability in yields was much less for crop 3 than for crops 1 and 2. The reduction can be explained in part by the harvest of crop 3 at earlier stages (6 to 7, Feekes) than the first two crops (10+), and by a reduction in the effect of soil borne pathogens on growth due to fumigation (see section 4.5). On the other hand, a phytotoxicity problem described above probably increased the variability in yields that would have been obtained without it.

Higher K content was measured in the barley for crop 3 than the first two because it was harvested at earlier stages. A lack of guidelines for assessing K deficiency for the stage at which the crop was harvested limited interpretation of the plant K concentrations. However, K contents were the lowest for the control pots of soil 4 followed by soils 3 and 2, with all three having deficient levels of exchangeable K after crop 2. The trends in plant K contents and exchangeable K of control pots for crop 3 were comparable to those for the first two. Other nutrients in the barley were not analyzed.

Except for the yield on soil 3 at the high rate of application, KCl added at both rates increased yields (Figure 5) relative to the control treatment. However, the KCl had no clear effects in reducing the variabilities in yield and root rot among soils within each KCl treatment (Figures 5 & 6). The treatments accounted for only 39% of the variability in yield. Differences among soil, K treatment and their interaction means for both yield and K uptake were significant (Table 8), as was reported for crop 1. The analyses were deemed valid given that only one of the 18 distributions for the six soils and three treatments was significantly anormal (.05 level).

Root rot ratings among all pots varied at most from clean (0) to slight (1). This is the only crop where root rot was less than slight. The correlation of barley yield to root rot is almost significant at the 0.05 level (Table 9), which indicates that only partial control of the pathogen(s) by chloroform fumigation was achieved. Differences in root rot severity among treatments were not significant, (Table 8). Neither main factor explained more than 20% of the variability in root

Table 8. Analysis of variance of data for crop 3

		Barley K uptake			Barley yield			Root rot scores		
Factor	DF	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F
Reps	2	32064	11.14	.000	2.958	7.94	.002	0.1304	1.552	.227
Soils	5	75370	26.18	.000	3.086	8.28	.000	0.1626	1.936	.115
K-Trmt	2	788025	273.76	.000	15.947	42.78	.000	0.0447	0.532	.592
S by T	10	11363	3.95	.001	1.650	4.43	.001	0.1025	1.220	.314
Error	33	2878			0.373			0.0840		

Table 9. Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 3 (control pots only)

	Mean barley K uptake				Mean barley yield			
Independ. Variable	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r
Exchang. K	2.071	0.196	0.943	.000	7.675 E-3	2.596 E-3	0.634	.011
Root rot	n.d.	n.d.	-0.059	.836	-0.956	0.460	-0.500	.058

n.d. not determined

rot, while the error term accounted for 56% of this variability. The ANOVA was deemed valid since the distributions of root rot means were normal according to the Kolmogorov-Smirnov test for goodness of fit.

Barley yield and K uptake were significantly affected by soil exchangeable K (Table 9). The data were not transformed because residuals adequately met tests of fit to assumptions recommended by Norusis (1983). Since barley K uptake was highly dependent on soil exchangeable K, it became necessary to determine what effect, if any, the fumigation treatment had on exchangeable K levels.

4.5 Effects of Fumigation on Soil K and Root Rot Fungi

The two soils which produced the most severe barley root rot in crop 1 were selected with two other soils for an incubation experiment in which chloroform was used to fumigate half of all samples for the four soils (see 3.3). Exchangeable K was determined at the start, and also after 2 and 4 weeks of soil incubation near field capacity, and at 21 to 23°C. The ANOVA indicated that differences in K among soil means were highly significant (variation among soils accounted for 99.4% of the variability in exchangeable K), whereas differences between fumigation treatment means were not significant (Table 10). Labels 'a','b','c' and 'd' in Figures 7a and 7b represent multiple comparisons of the interaction means (soil by treatment, with error of the means = 2.70), and show no differences in exchangeable K between fumigated and control treatments of each soil.

Robustness of the test procedures used above was relied on to provide valid conclusions, as recommended by Zar (1984), since one of the eight soil by treatment means was significantly anormal. The distributions of the control and fumigated treatment means were both anormal and positively skewed, however, so an ANOVA was also done on the log transformation of the data. The two treatment means were again not significantly different, and soil means after transformation were still significantly different. Fumigation with chloroform thus had little effect on exchangeable K, which is the most widely used index of plant K availability (see section 2.2).

The effect of fumigation on the population of spores of Bipolaris sorokiniana was examined using two reps of the same four soil samples.

Figure 7a. Mean exchangeable NaOAc-K of fumigated and non-fumigated soil samples 4 and 6, at 3 different incubation times

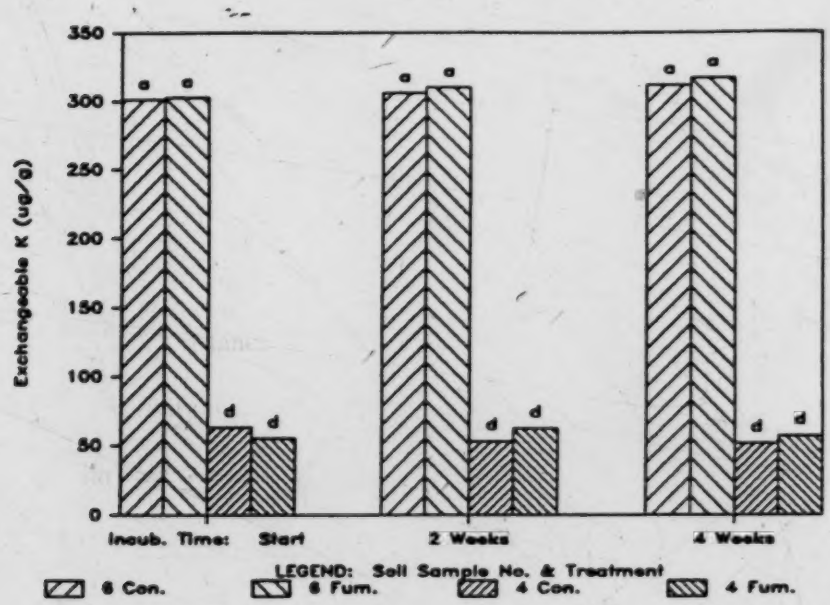


Figure 7b. Mean exchangeable NaOAc-K of fumigated and non-fumigated soil samples 2 and 3, at 3 different incubation times

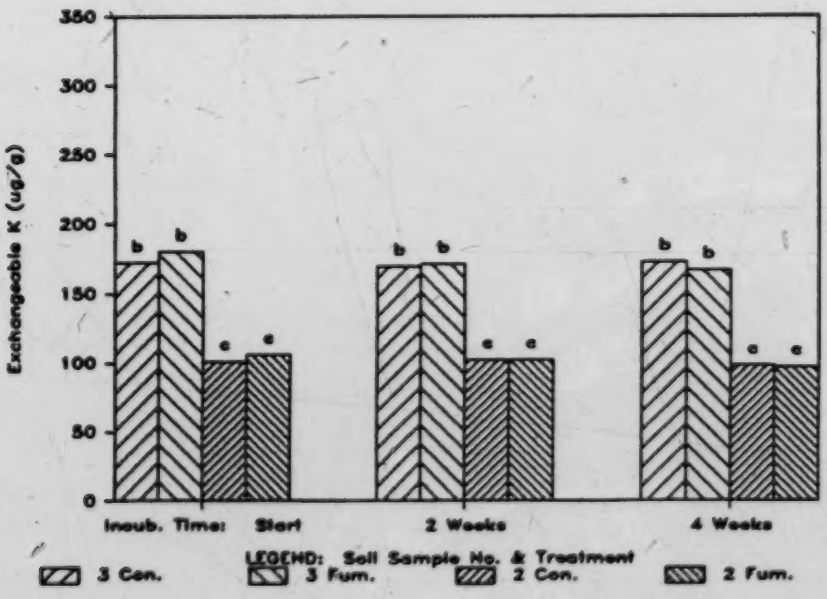


Table 10. Analysis of variance of exchangeable soil K and Bipolaris sorokiniana (major root rot pathogen) spore count data from soil incubation experiment

	Exchangeable K ($mg*kg^{-1}$)				Spore Count Data			
Factor	DF	Mean Squ.	F Test	Signif. of F	DF	Mean Squ.	F Test	Signif. of F
Inc.T..(I)	2	10.18	0.2	0.825	--	---	---	---
Fumig..(F)	1	78.13	5.8	0.137	1	2162.25	80.83	0.000
I by F	2	13.41	0.3	0.776	--	---	---	---
Soils...(S)	3	216971.51	1607.2	0.000	3	1734.42	64.84	0.000
I by S	6	135.00	2.6	0.031	--	---	---	---
Soils by F	3	5.77	0.1	0.964	3	347.42	12.99	0.002
I by S by F	6	65.71	1.3	0.298	--	---	---	---
Error	48	52.54			8		26.75	
TOTAL	71	9222.30			15	574.78		

Reliability of the method used to extract spores (see section 3.3) was evaluated by Duczek (1982) who found that 99% of isolates obtained from prairie soils by this method were indeed those of B. sorokiniana. Efficiency of the method in extracting the spores, however, was reported to be only 56% (Duczek, 1981). Nevertheless, Duczek (1982) maintained that the method was satisfactory for comparative studies of conidial densities among soils, or whatever soil treatments used.

Samples for spore counts were taken only before the incubation period, thus time was not included as a variable in the experiment. The data set was not transformed since the overall data and that split by treatment satisfied the Kolmogorov-Smirnov test for goodness of fit to normality. Up to 85% of the variability in the spore data was due to differences among soils (S) and fumigation (F), and is reflected by the highly significant F ratios (Table 10). Spore counts from soils 2, 3 and 4 were significantly decreased two to three times by chloroform fumigation. The non-fumigated samples of soils 2 and 3, which produced the most severe root rot among the six soils in crop 1, contained the greatest number of B. sorokiniana spores. Soil sample 6 contained the fewest spores of the pathogen, and produced the least root rot in crop 1. These observations support the theory that variation of root rot among soils in the greenhouse experiments was due to different levels of infestation in the soils.

Spores of B. sorokiniana extracted from fumigated and control soil samples, which were incubated for 16 to 20 h in potato dextrose agar, revealed lower spore viability in extracts from the fumigated samples than from the controls. There were more spores that appeared to be lysed or that failed to germinate in the extracts from the fumigated samples. Therefore, not only did chloroform fumigation reduce the conidial density of the root rot pathogen, it also reduced the viability of the spores that remained. Incomplete eradication of viable root rot spores, however, confirmed that chloroform fumigation did not completely control the disease.

4.6 Observations and Analysis Of Barley Crop No. 4

The maximum temperature reached on several non consecutive days during the growth period (from late Feb. to mid April) was 27°C. A maximum of 32°C was recorded once in the sixth week after emergence due to inadequate artificial cooling of the chamber, but only one pot among 63 showing some temporary stress. The minimum daily temperature was usually maintained at 14°C for most of the 8 weeks. An effect of either minimum or maximum temperature stress on the barley was probably avoided. Moisture stress was minimized by frequent watering of all pots.

None of the pots was fumigated prior to seeding the fourth crop, as was done before the third. Empress barley was seeded after an additional 200 and 400 ug g^{-1} K were added to the mid and high KCl treatments, respectively. Emergence of the fourth crop was very even with less than half a day separating the first and last coleoptiles to emerge within a rep. Stunting was first observed from 1 to 2 weeks after emergence on one of the three control pots for each of soils 2 and 3. Brown lesions on the base of stems and subcrown internodes of culled plants from pots with stunted barley resembled symptoms of seedling blight, which is an early phase of common root rot (Martens et al., 1984). The affected barley still grew, but was more stunted than that on the other controls of both soils. The mean yields for the controls of soils 2 and 3 (Figure 8) were not adjusted to compensate for the stunting, probably caused by seedling blight.

Characteristic K deficiency symptoms on barley leaves in this crop were masked by chlorosis and necrosis that progressed from leaf tips and produced yellow leaf tissue with brown lesions. These symptoms appeared to different degrees at random on most pots by harvest time. Most of the barley reached stages 10.0 to 10.1 (Feekes scale) 8 weeks after seeding, and was harvested at this time. Besides the stunting associated with the blight described above, yields were lower on the controls than the two KCl treatments for all soils (Figure 8), which implied depletion of available K in all of them. Effects of cropping on exchangeable K of the soils is discussed in section 4.8.

Barley plants from the control pots of soils 2, 3 and 4 either had deficient or nearly deficient K contents based on Manitoba Provincial

Figure 8. Mean dry matter yields (3 reps) of barley from crop 4 for all combinations of KCl treatments and surface Ap samples

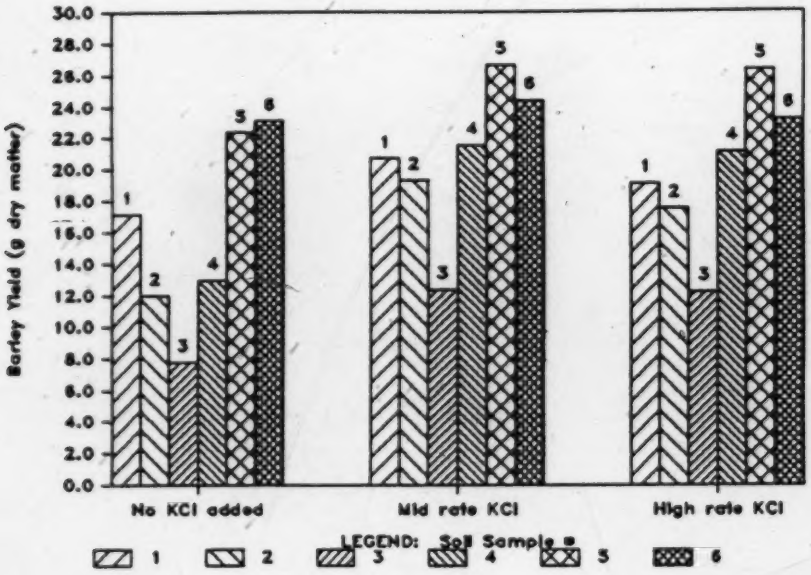
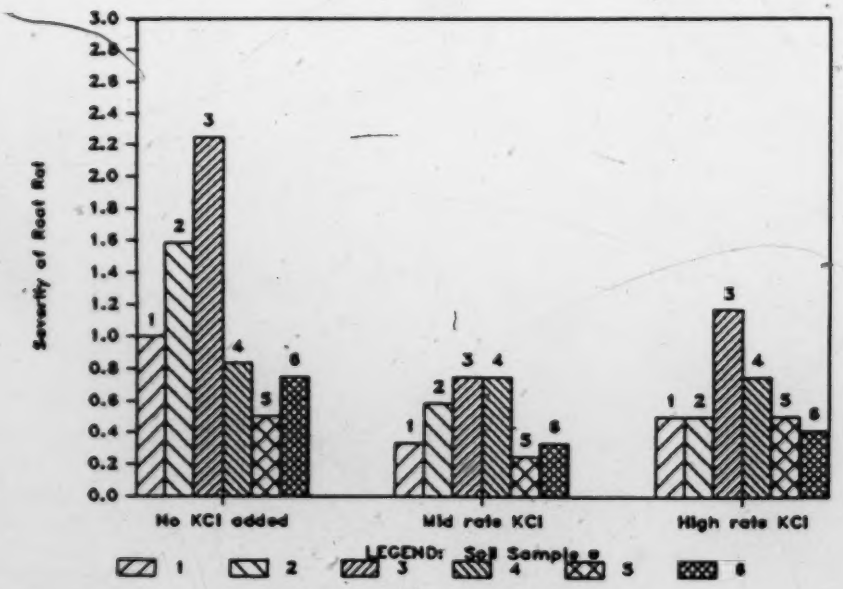


Figure 9. Mean root rot severities (3 reps) on barley of crop 4 for all combinations of KCl treatments and surface Ap samples



Soil Testing Lab (MPSTL) guidelines. Levels of K in barley from the other control pots did not show K deficiency, despite exchangeable K values which were lower than the 125 ug g^{-1} critical level used to delineate soil K deficiency in Alberta. Robertson et al. (1985) indicated that the present critical value was higher than the level which they found (80 ug g^{-1}) to be more appropriate to categorize K deficiency in Alberta soils. The K contents in barley from all pots which received KCl were satisfactory, according to MPSTL guidelines. Trends in exchangeable K and plant K contents were comparable to results from the previous crops, but more variability was observed among reps in this crop.

The largest yield response to applied KCl was from soil 4, which contained the lowest exchangeable K (Table 11), and produced barley with some of the lowest K contents. These findings agree with the results from the three previous crops. The next two largest yield responses to KCl were for soils 2 and 3, which contained the next two lowest levels of exchangeable K among controls. These responses are consistent with only some of the results from the two previous crops.

Highly significant differences among soil and K treatment means were detected by the ANOVA of crop 4 barley yield and K uptake data (Table 12). Variation among treatments accounted for 70% of the variability in K uptake, whereas variation among soils accounted for 72% of the variability in yield. Differences among the means of soil by treatment interactions were highly significant for K uptake, and only significant at 0.10 for yield. The robustness of ANOVA was relied on to provide valid F tests since three of the 18 distributions of means for the soil by treatment combinations were anormal, based on the Kolmogorov-Smirnov test for goodness of fit to normality.

A comparison of Figures 8 and 9 to Figures 5 and 6 indicates some increases in the variability of barley yield and root rot from crop 3 to crop 4. Harvesting the fourth at later stages of growth than the previous one should explain part of the increases in the variability. Because fumigation was not repeated before seeding crop 4 and it did not eradicate all root rot spores, part of the increases should also reflect an increase in root rot infestations in the soils.

Table 11. Mean barley K uptake (mg/kg soil) and mean exchangeable K (mg/kg) of 4 crops

Soil No.	Fert. KCl Treatment	Barley K uptake for each crop				Mean NaOAc exch-K for each barley crop				
		# 1	# 2	# 3	# 4	Initial	# 1	# 2	# 3	# 4
1	Nil added	81.5	75.1	124.0	133.1	278.3	189.6	160.4	70.9	80.4
1	Mid rate	104.0	145.2	220.8	326.8		341.4	228.9	197.7	138.1
1	High rate	134.2	162.5	238.9	346.3		497.8	359.7	426.2	484.6
2	Nil added	15.5	80.1	60.0	42.0	96.2	92.0	57.2	32.0	53.7
2	Mid rate	63.0	152.3	188.0	267.5		173.2	84.8	94.1	99.6
2	High rate	93.1	201.7	211.8	304.7		284.2	155.8	262.1	299.8
3	Nil added	7.0	78.0	39.4	25.9	77.4	83.4	51.6	33.2	58.7
3	Mid rate	30.2	191.4	159.9	183.6		184.0	81.1	109.4	120.6
3	High rate	37.4	226.7	169.7	227.9		297.4	123.7	267.4	390.6
4	Nil added	28.4	31.4	40.9	49.4	58.8	60.7	60.1	15.2	40.0
4	Mid rate	220.8	59.0	227.2	277.6		74.7	64.3	36.1	47.0
4	High rate	297.1	149.3	306.4	438.1		139.7	76.5	114.3	87.0
5	Nil added	183.2	157.7	124.9	143.0	490.0	325.5	201.9	103.2	71.5
5	Mid rate	300.0	173.0	215.9	339.4		446.7	289.2	239.6	137.7
5	High rate	325.7	223.2	204.4	421.0		594.0	452.7	596.0	544.2
6	Nil added	177.2	110.4	95.3	128.9	285.3	151.2	110.6	40.2	62.4
6	Mid rate	261.0	168.7	197.3	296.1		256.5	161.6	141.9	110.5
6	High rate	298.8	212.8	236.5	367.7		457.0	289.3	351.8	366.6

Table 12. Analysis of variance of data for crop 4

		Barley K uptake			Barley yield			Root rot scores		
Factor	DF	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F	Mean Sq.	F test	Sig. of F
Reps	2	9565	1.55	.227	2.90	0.69	.510	0.0104	0.06	.945
Soils	5	370320	59.92	.000	240.18	56.93	.000	1.1160	6.05	.000
K-Trmt	2	2571390	416.04	.000	123.63	29.30	.000	2.1293	11.54	.000
S by T	10	20135	3.26	.005	7.67	1.82	.095	0.2670	1.45	.201
Error	34	6181			4.219			0.1844		

Table 13. Multiple regression of mean barley K uptake and mean yield on exchangeable K and severity of common root rot of barley for crop 4 (control pots only)

	Mean barley K uptake				Mean barley yield			
Independ. Variable	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r	B Coef.	Std. Dev. B coef.	Partial 'r'coef.	Sig. of r
Exchang. K	4.211	0.525	0.900	.000	0.104	2.577 E-2	0.720	.001
Root rot	-65.032	21.916	-0.608	.010	-4.090	1.075	-0.701	.002

Root rot symptoms on subcrown internodes (overall data) varied from very slight to slight for most pots which received KCl, to moderately severe (rating of 2.5) for some control pots of soils 2 and 3 (Figure 9). The greatest increases in root rot severity from crops 3 to 4 were for the control treatment of soils 2 and 3. The rooting systems from the latter pots were developed less extensively than roots from the other four soils, as was observed for the first crop. Increases in root rot in soils 2 and 3 for the two KCl treatments were more subdued than for the controls. Differences in root rot severity among soils and KCl treatments for crop 4 were highly significant (Table 12), which agrees with the results for crop 1. The ANOVA of root rot data was considered valid because distributions of means for soils and treatments (9 in all) were not significantly anormal, based on the Kolmogorov-Smirnov test for normality (0.05). Significance of the effect of KCl on barley root rot is discussed in section 4.9.

Multiple regression of crop 4 data (Table 13) resembles that for crop 1 (Table 5), in that both reflect the highly significant effects of exchangeable K and root rot on both barley yield and K uptake. An effect of root rot on uptake precluded comparisons of the K fertility of the soils. Since exchangeable K was determined for control pots only before seeding crop 4, regressions are reported for the data of the control treatment (no KCl). Slopes (B coef.) of the regressions (Table 13) indicate that yield and K uptake are positively correlated to exchangeable K, and that both barley variables are negatively correlated to severity of root rot. Crop 4 data were not transformed because residuals met tests for violations of assumptions recommended by Norusis (1983).

4.7 Correlation of Barley Variables With Soil K and Root Rot

Correlations of yield on exchangeable K and root rot for crop 4 were the best among crops. The closest negative correlation of barley K uptake on root rot among crops was also from crop 4. The closest correlation of K uptake to exchangeable K, however, was obtained for crop 3 (Table 9), wherein root rot explained less than 1% ($r=-0.059$) of the variability in K uptake. The poorest correlations of yield on root rot and exchangeable K were from crop 2, probably because

fumigation was done on only two reps of soils 2 and 3. Exchangeable K measured before seeding each crop (control only) explained from 75% of the variability in K uptake for barley crops 1 and 2, to 90% of the same variability for crop 3 data. Regression of either barley yield or K uptake on exchangeable K was reported for K measured before cropping, as is normally done in the literature.

Correlation coefficients for K uptake on exchangeable K reported in this study compared favorably with a range of 'r' values seen in the literature for most pot experiments (r= 0.76 to 0.98). The highest 'r' values (r= 0.97-0.98) were reported by Sinclair (1982), but only 3 different Scottish soils were used in that study. Correlations generally tend to be lower, yet still significant, when a wider range of soils is included in K uptake trials.

Relationships of soil K with crop yield are often poorer than with K uptake, and are sometimes insignificant, probably because of 'luxury consumption' of K. In the same study cited earlier, Sinclair (1982) reported 'r' values of 0.51 to 0.85 for yields of ryegrass regressed on soil K. The correlations of exchangeable K with barley yield were also lower in this study compared to those of exchangeable K with crop uptake, but root rot also had a significant effect on yields. By itself, common root rot accounted for 67% of the variability in yields and 57% of the variability in K uptake values for the first crop. Reports in the literature of the effects of root rot, or any other disease, on crop K uptake are unknown to this author.

Studies from western Canada on soil K and its uptake by crops in the field have often showed poor and insignificant correlations of K uptake with extractable forms of soil K (Halstead et al., 1970). Lopetinsky (1977) processed a large data set collected from K uptake trials done in Alberta, and obtained a poor (r=-0.33) correlation between extractable K and crop responses to fertilizer K. He suggested that soil parameters besides extractable K be considered to improve the accuracy of predicting soil K requirements to crops. Harapiak (1979) observed that crop responses to K were related better to ranges in soil texture than intervals in exchangeable K. He also speculated that responses on soils with high extractable K, which occur in southern Alberta and Montana, might be related to frequency of warm

weather and drought stress, which are conditions that favor severity of dryland common root rot (Martens et al., 1984).

Drought stress, root rot, KCl fertilizer and their interactions might have affected crop responses to KCl observed in earlier studies. Given the poor correlations of K uptake with extractable K mentioned above, and the highly significant effect of root rot on barley reported in this study, it is possible that root rot was an unknown which contributed to the poor and sometimes insignificant correlations obtained in earlier work. The effects of plant diseases on nutrient uptake deserve more scrutiny in future studies.

4.8 Exchangeable K, Successive Cropping and K Uptake

Exchangeable K values determined before any cropping of samples 2, 3 and 4 (Table 11) were deemed deficient for cereal crops, based on a critical level of exchangeable K (125 ug g^{-1}) used by the ASANL. Exchangeable K of control samples 1, 5 and 6 were reduced by barley K uptake to deficiency levels after crop 3, assuming that equilibration of exchangeable K occurred before sampling. Increases in exchangeable K of control samples after crop 4 reflect in part the ability of the soils, except for soil 5, to replenish (buffer) plant available K. Soil K buffer power is also reflected by greater K uptake from control samples than corresponding reductions in exchangeable K from one crop to the next. MacLean and Brydon (1971), Munn and McLean (1975), and Singh et al. (1983), among others, have recognized the importance of soil K release from non-exchangeable forms in buffering available K. Since comparisons of K uptake among the soils used was obscured by significant effects of common root rot on uptake of soil K, valid comparisons among soils of K buffering power were not possible.

Anghinoni et al. (1981) found that P and K uptake rates of wheat decreased with plant age, so that the pool of exchangeable K might be replenished more by non-exchangeable K under a more mature crop stand than a younger one. It is speculated that the low exchangeable K values of the control pots measured after crop 3 might partially reflect a state of greater soil K depletion by the younger stands of barley (stages 6 to 7), than by the more mature barley of the other crops (stage 10+). Time of soil sampling after harvest might also

account for the higher exchangeable K values following crop 4, but it did not appear to have significantly affected soil K when the data for each crop are examined one at a time.

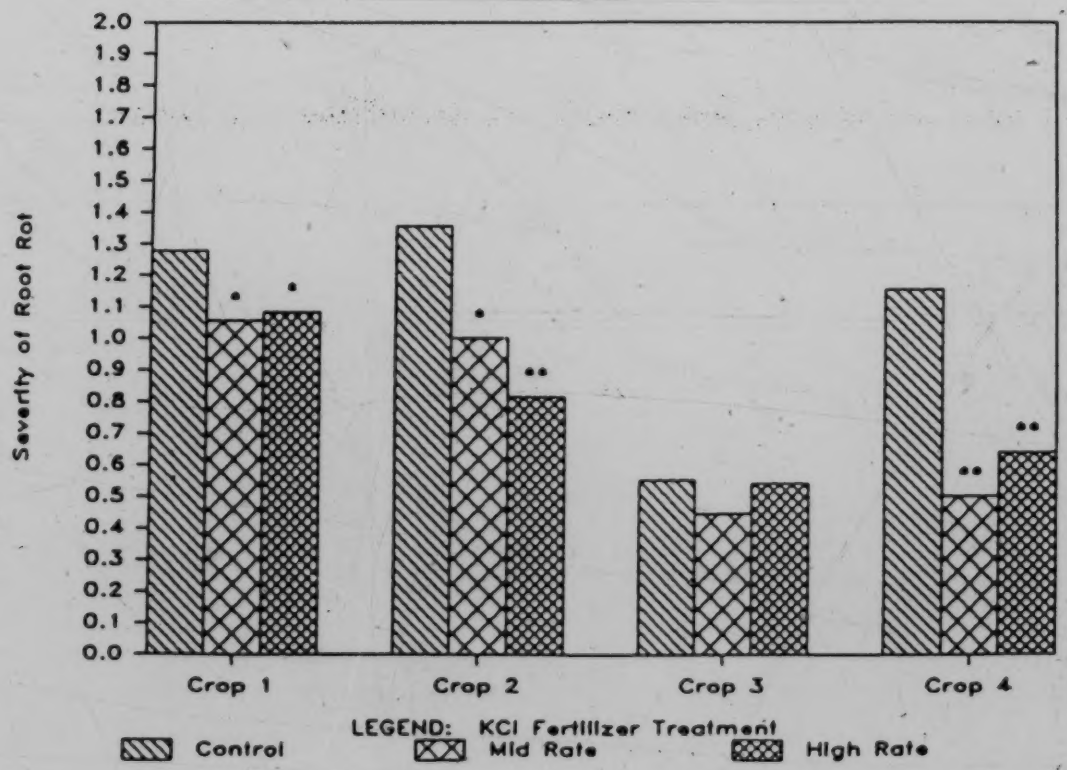
4.9 Effect of Fertilizer KCl on Barley Root Rot

Differences in root rot among soils were highly significant except for crop 3, where their significance was only 0.115 (Table 8). Likewise, differences in root rot means among K treatments were significant except for crop 3. These observations can be attributed to the effect on root rot of fumigation, which was done before seeding crop 3. The lack of significant interactions (soils by KCl treatment; 0.05 level) permitted multiple comparisons of root rot means among treatments for all crops (Figure 10), which were confirmed with orthogonal contrasts.

There were no significant differences in root rot severity among KCl treatment means for crop 3 because of an overall reduction in disease due to fumigation (sections 4.4 and 4.5). Thus no significant effect of KCl on root rot severity was observed when it was no more than slight (crop 3). Mean root rot severity of the control treatment was significantly greater for each of crops 1, 2 and 4 than root rot means of the mid and high KCl treatments, which were not significantly different from each other. While root rot significantly reduced barley yield and K uptake, especially on soils 1, 2 and 3 of crops 1 and 4 (see sections 4.2 and 4.6), the mid and high rates of added KCl significantly reduced disease severity (Figure 10). Therefore, apart from a direct benefit to barley of applying K, which one would expect on the K deficient soils (2, 3 and 4), the KCl added in crops 1 and 4 is believed to have indirectly benefited the barley grown on soils (2 and 3) infested with common root rot, through disease suppression.

Only KCl fertilizer was used as the initial treatment to assess K fertility of the soils in this study, because crop yield and K uptake responses to applied K alone were anticipated when the experimental design for the greenhouse was first developed. A decision was made to use the same design for subsequent greenhouse experiments, which excluded use of a non-chloride source of K fertilizer. Because KCl was not compared to another K fertilizer, it is impossible with the

Figure 10. Comparison among KCl treatment means of root rot severity for each barley crop; significance of differences denoted (control vs mid and high) are *-0.05, **-0.01.



results obtained to distinguish the direct benefits to barley of either or both K^+ and Cl^-, from an indirect benefit of KCl through suppression of root rot, which has been reported before by others.

Effects of KCl on root rot of cereals reported in the literature are diverse. A number of researchers, namely Garvin et al. (1981), Shefelbine et al. (1986), Timm et al. (1986), and Goos et al. (1987) found that Cl^- reduced common root rot of barley in fields where the disease was a problem. On the other hand, Skogley (1985) and Fixen et al. (1986a) reported that a low incidence of root rot was not affected by the addition of KCl, even though some yield responses of cereals was attributed to Cl^-. Fixen et al. (1986b) concluded that the benefit of added Cl^- to wheat was due to a soil deficiency of the anion. Goos et al. (1987) observed significant reductions of common root rot by KCl at 2 sites in North Dakota where the disease severity was greater than slight, but found no effect on root rot of either KCl or a fungicide, at another site where the disease severity was less than slight. A clear explanation of the diverse effects of added KCl on common root rot and crop growth remains unknown. More research of an interdisciplinary nature is needed to help resolve how KCl might indirectly and directly benefit crop plants when both (a) soil nutrient deficiency(ies) (either or both K^+ or Cl^-) and common root rot are present.

5. SUMMARY AND CONCLUSIONS

Six surface soil samples with loamy textures from central Alberta were selected to investigate the relationship between K availability to plants and several soil properties. The samples were taken from sites of previous field experiments. Four samples from imperfectly to poorly drained areas were considered to be K deficient, while the other two were apparently not K deficient.

Greenhouse experiments, which included two rates of added KCl and a 'control', were designed to compare barley yield and K uptake with extractable soil K. Exchangeable K was first extracted with NaOAc and NH_4OAc to compare the effectiveness of the two methods as indices of K availability. After observations on crop 1 indicated that root rot was a serious problem, the two soils which produced the worst root rot were fumigated with chloroform before seeding crop 2. Fumigation of all soils was done before seeding barley crop 3, but was not repeated for the fourth. A soil incubation experiment was also done to examine the effects of fumigation on soil K and a major root rot pathogen. The probability of temperature and moisture stresses on the barley among the four crops was the greatest for the first, because of extremes in temperature experienced during the growth period. Temperature and moisture stresses on barley were minimized if not avoided for the three crops that followed.

Exchangeable K extracted with both NaOAc and NH_4OAc was highly correlated (r=0.918 & 0.901, respectively) with K uptake of crop 1. NaOAc was selected for subsequent use to avoid fixation of NH_4^+ by clay minerals. K contents of plants from crop 1 were marginal for the two soils that contained less extractable K than the critical value of 125 $ug \cdot g^{-1}$ used by the ASANL. Exchangeable K of control samples was consecutively reduced by crops 1 to 3, but increased after crop 4, except for one soil, which reflects the K buffer power of the soils. Significant effects of common root rot on K uptake and variability in disease severity among soils obscured the determination of K buffer power of the soils, which were not calculated.

Fertilizer KCl increased yields of barley in the first experiment, but did not eliminate yield differences among soils, which accounted

for 91% of the variability in yields. Since only a few plants were affected by leaf diseases, and nutrient deficiencies explained little of the variability in yields, the roots were examined for diseases. Observations indicated that reductions in yield and in tillering corresponded to root rot severity. Exchangeable K had a significant positive effect on both barley yield and K uptake, whereas root rot had significant negative effects on both. Barley yields were more highly correlated with root rot severity than with exchangeable K.

An adverse effect on barley from the application of insecticidal soap at 2.5 times the recommended rate, and chloroform fumigation of two soils were two additional sources of variability in crop 2 data. The largest yield response to initial applications of KCl was no more than twofold, whereas dry matter production on the fumigated soils was increased by two to four times. Yield increases from fumigation corresponded to decreases in root rot severity from moderate to slight. Exchangeable K was highly correlated with K uptake, but neither exchangeable K nor root rot were highly correlated with yields, probably because of the increases in variability of the data.

All pots were fumigated before seeding crop 3 to try to eliminate the effect of root rot. Yield responses to fertilizer KCl were more subdued in this crop than in crops 1 and 4, in which root rot had significantly affected yields. An unidentified side effect of fumigation caused some stunting of barley on a few pots. Fumigation did not significantly affect exchangeable K, which was slightly more highly correlated ($r=0.94$) with K uptake than that in crops 1 and 2. Fumigation significantly reduced the viability and inoculum level of a main root rot pathogen, but failed to eradicate all of its spores in the soils. Its persistence meant that the effect of root rot on yield was almost significant (0.05 level) after fumigation, but differences in root rot among the soils were not. Smaller yield responses in crop 3 were likely attributed to less disease suppression by the KCl, since root rot was less of a factor than in crops 1 and 4.

There was an increase in the variabilities of barley yields and K uptake from crops 3 to 4. Variation among K treatments accounted for 70% of the variability in K uptake for crop 4, which was about the same as for crop 3, but was greater than the effects of KCl noted in

crops 1 and 2. About 72% of the variability in yields, however, was attributed to variation among soils, which explained more variability in yield than in crops 2 and 3. Since fumigation was not repeated before seeding crop 4, there was an increase in root rot severity from crops 3 to 4, especially for the two soils which produced the worst root rot in crop 1. Seedling blight, an early phase of root rot, was observed in this experiment on two control pots, and caused the most severe yield reductions. Exchangeable K and root rot both had highly significant effects on barley yield and K uptake. Correlations of yield and of K uptake with exchangeable K were comparable to values reported in the literature. Correlations of exchangeable K with barley yield were lower than with K uptake, probably because of luxury consumption of soil K, and a greater effect of common root rot on yield than on K uptake.

Fertilizer KCl significantly reduced the severity of root rot in crops 1 and 4, in which the disease had significant negative effects on barley yield and K uptake. The KCl had little effect on root rot in crop 3 because fumigation reduced root rot severity to no more than slight. The benefit to the barley of disease suppression by KCl was not distinguished from the benefits of adding the two nutrients, since alternative sources of K^+ and Cl^- were not used.

In conclusion, although amounts of soil K extracted with NaOAc and NH_4OAc at pH 7 differed, the correlations of K extracted by the two methods with barley K uptake were very similar. Exchangeable K of soils which did not receive any KCl was depleted by cropping, but the release of non-exchangeable K buffered the supply of K to crops. The exchangeable K of soils was affected little, if any, by chloroform fumigation. Fumigation reduced the number of viable spores of B. sorokiniana, a major root rot pathogen, but failed to eliminate the negative effects of the disease on yield. Either repeated fumigation or a better method of controlling root rot would have been required to eliminate its effects on growth and nutrient uptake.

Effects of added KCl on barley in crops 1 and 4, when root rot significantly affected it, were probably a combination of plant nutrient responses to either K^+ or Cl^-, and a benefit to barley by suppression of root rot. There is a lack of agreement among reports

in the literature on the benefits of fertilizer KCl to cereal crops. Suppression of common root rot by KCl was insignificant when the disease was no more than slight (crop 3), as was reported by Fixen et al. (1986a) and Goos et al. (1987). When root rot severity is greater than slight, however, added KCl can suppress the disease and its effects on a crop (Goos et al., 1987). Common root rot was probably a factor in earlier studies of K uptake and extractable K, and possibly contributed to the poor correlations obtained between the two. More research is needed to resolve how KCl can indirectly and directly benefit cereal crops when both a nutrient deficiency (either or both K^+ and Cl^-) and a root disease significantly affect growth.

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